THE UNIVERSITY OF ALBERTA

A STUDY OF LIGHTNING IN THE WHITECOURT FOREST OF ALBERTA

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "A Study of Lightning in the Whitecourt Forest of Alberta" submitted by A. Maarouf, in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The Whitecourt Forest in the Province of Alberta was selected for a study of the relationship between the atmospheric parameters and the occurrence of lightning over the region. The surface and upper-air data from Stony Plain, Alberta were taken to represent the air overlying the Whitecourt Forest. The summer days for a period of five years were classified into major, minor, and no-lightning days. The mean values, range of values, and the frequency distributions for some stability indices and forecasting parameters are presented for each lightning class. A linear relationship between the forecasting parameter and the probability of lightning occurrence is given for most of the indices studied. An upper-wind analysis is made for winds at the standard isobaric levels 850, 700, 500 and 300 mb. The effect of the vertical wind shear on thunderstorm occurrence is also noted.

The study shows that the weather parameters and stability indices derived from Stony Plain data distinguish between lightning and no-lightning days in the Whitecourt Forest. The results can be used to give a more successful forecast of lightning.

ACKNOWLEDGEMENTS

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CHAPTER ONE

INTRODUCTION

Lightning activity is a very common phenomenon in Alberta summer storms. Because lightning is a direct cause of forest fires when dry conditions are present, the Department of Lands and Forests in Alberta has made extra efforts to improve forecasts of lightning. Providing the forestry staff in the field with a reliable forecast of lightning occurrence along with the accompanying weather conditions such as wind, gusts, precipitation, etc., the necessary preparations can be made to prevent the extension of a possible fire and minimize the efforts expended and loss of money.

In order to improve the prediction of lightning occurrence, it is necessary to study the weather conditions prior to and during the lightning storm for a large number of storms. Conclusions may then be made about the favorable conditions for lightning occurrence and also some stability indices can be determined to provide the forecaster with a useful guide about the probability, the intensity, the time, and the area of lightning occurrence.

In this study the area of Whitecourt Forest, as shown in Figure 1.1, was selected to apply some of the stability indices and forecasting parameters which have proved useful in predicting severe thunderstorms over many localities of

the world (see for example Miller, 1967). The research was made to discover a distinction between the values of these indices on days of lighning activity and days free of lightning in the Whitecourt Forest.

SOURCES OF DATA

The Alberta Forest Service operates ten fire lookouts in the Whitecourt Forest. The lookout men whose primary job is detecting forest fires are also providing the weather division of the Alberta Forest Service with some useful information about the prevailing weather conditions. The observational program starts in late April and terminates in early October every year. The lookout men do not observe during the night. Lightning is one of their main concerns in watching the weather. A lookout man who observes lightning within 25 miles completes a storm report and mails it to the headquarters in Whitecourt. These reports were used in this study to make a subjective classification of lightning and no-lightning days.

The meteorological upper air station of Edmonton Stony Plain, which is operated by the Atmospheric Environment Service, is the nearest upper air station to the area of concern. It is also believed that Edmonton upper air data reliably represent the air overlying the Whitecourt Forest on most if not all summer days. Data from Stony Plain (766 m above MSL) were then used to study the vertical temperature, moisture, and wind distribution and to determine the values

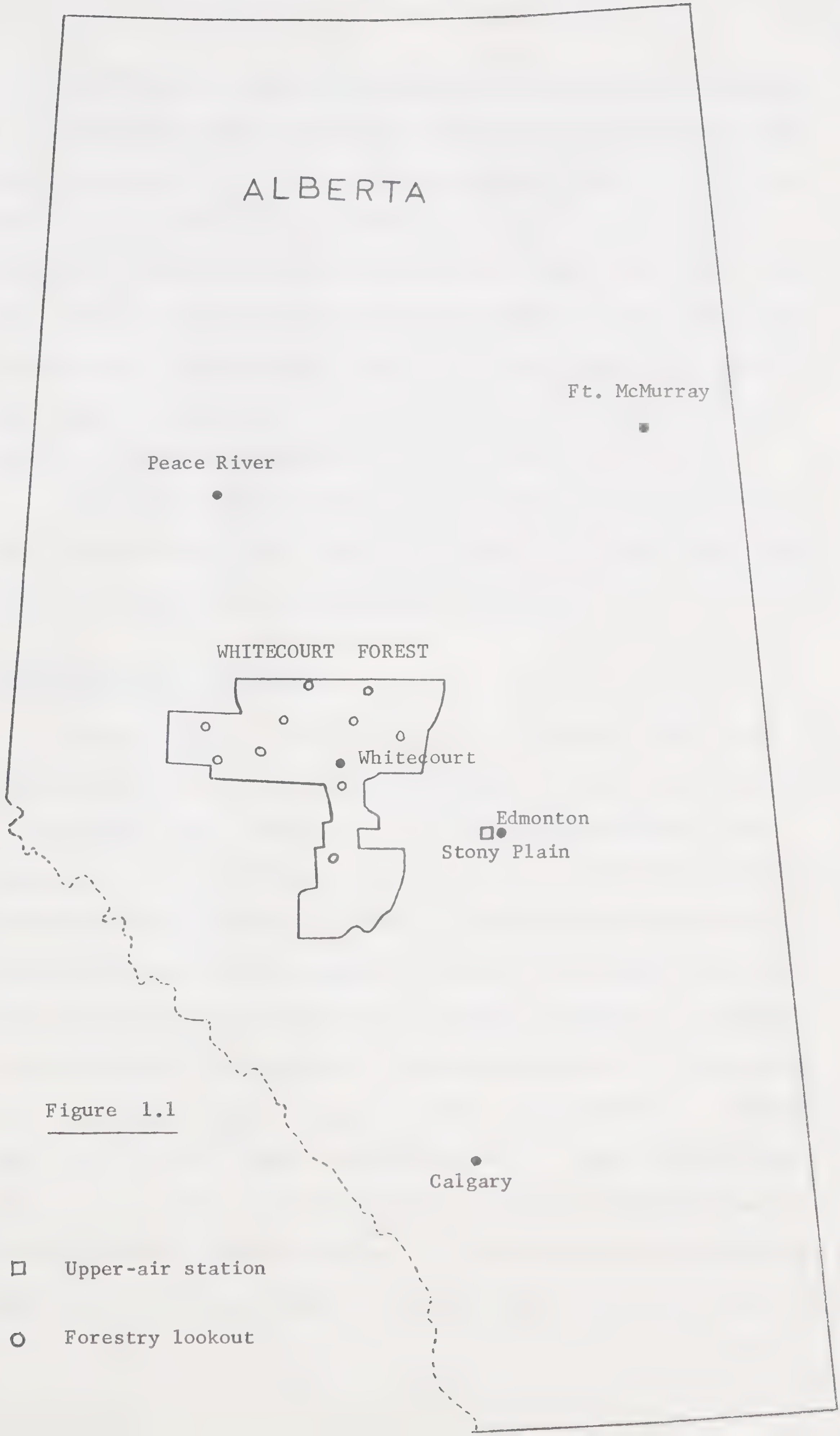
ALBERTA
Ft. McMurray
Peace River
WHITECOURT FOREST
Whitecourt
Edmonton
Stony Plain
Calgary
Upper-air station
Forestry lookout

Figure 1.1

of the different stability indices and weather parameters.

The months of June, July and August over a period of five years, 1966 to 1970, constituted a total of 460 days with which to make the required analysis of lightning weather. Because the meteorological station of Stony Plain measures the upper air weather parameters twice every day, at 0500 and 1700 Mountain Standard Time, these were the two observations used to study the weather conditions, on days of lightning and days of no lightning.

The approximate locations of the fire lookouts of the Whitecourt Forest are shown in Figure 1.1. The figure shows also the location of Stony Plain, Alberta.

CLASSIFICATION OF DAYS

Among the 460 days used in this research there was a limited number of days characterized by lightning activity in the Whitecourt region. The first classification was made for each individual lookout. Any report from the look-out man stating that any type of lightning was observed within 25 miles at any time of a day identified this day as a "lightning day" for this specific lookout. A further classification was made for the whole region. A lightning day for 50 per cent or more of the total number of lookouts was said to be a "major lightning day". Days having less than 50 per cent of the lookouts reporting lightning were termed "minor lightning days". A third class was made of those days on which none of the lookouts reported lightning

activity. These were said to be "no-lightning days". According to this classification, there were 99 major days, 100 minor days and 261 no-lightning days.

ANALYSIS OF DATA

The temperature at the surface and at the upper pressure levels, the station surface pressure, the low-level moisture, the height of 500-mb level and the upper wind data were given at 0500 and 1700 MST for all days in each class. These weather measurements from Edmonton Stony Plain in addition to other stability indices derived from them were used in the following analysis to determine any significant change in their values, pattern or behaviour between days of no lightning and days of lightning activity in the Whitecourt Forest. Also, an attempt is made to provide the forecaster with a guide in making his prediction of lightning, for example, by determining the threshold values of the stability indices for the occurrence of a lightning day, by determining a linear relationship between each stability index and the probability of lightning occurrence, and by studying the vertical wind pattern and wind shear on lightning days for each of 0500 MST and 1700 MST observations.

The reader should note that the "significance" of the differences between values of indices of the various lightning classes has not been determined by means of statistical tests. The term "significantly different" is used, however, in this work to indicate that the observed differences seem to be large enough to suggest their usefulness in practical applications.

CHAPTER TWO

STABILITY INDICES AND FORECASTING PARAMETERS

THE VERTICAL TEMPERATURE PROFILE

The thermal structure of the air plays an important role in thunderstorm occurrence. The actual temperature controls the ability of the air to contain and transport moisture. In nearly all cases of major severe thunderstorm outbreaks, little cooling occurs at 500 mb over the threatened area. In reality, slight warming through advection or the release of latent heat is likely to occur. As long as heat and moisture are added to the lower levels of the air mass, slight warming in the middle and upper levels will not increase the actual stability. Table 2.1 gives the mean temperature at the surface and at the upper pressure levels for major, minor and no-lightning days.

Figures 2.1 and 2.2 show the temperature distribution given in Table 2.1 for 0500 MST and 1700 MST, respectively, plotted on a tephigram. It is seen from the figures as well as from Table 2.1 that the temperature is warmer at almost all levels for the days of lightning activity than for the no-lightning days. It is also clear that the warming during the day takes place at the lower levels on lightning days with little change at the higher levels. On the other hand, a significant increase in temperature occurs at higher levels on the days free of lightning. On days of minor lightning where the warming at the lower

TABLE 2.1

Mean temperature at the surface and upper pressure levels, classified according to thunderstorm occurrence.

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
SURFACE	12.1	11.7	9.7	21.2	19.3	18.9
900 mb	14.9	14.1	11.9	19.0	17.1	16.2
850 mb	13.5	12.5	9.4	14.8	12.9	11.8
800 mb	10.1	9.2	6.1	10.9	8.9	7.5
700 mb	2.0	1.3	-1.0	2.7	1.2	0.2
600 mb	-6.7	-7.0	-8.2	-6.1	-6.9	-7.0
500 mb	-15.8	-15.9	-16.8	-15.3	-16.1	-15.7
400 mb	-27.7	-27.7	-28.4	-27.1	-27.8	-27.6
300 mb	-43.2	-42.8	-43.7	-42.5	-42.8	-42.7

layers is not as much as it is for other days, the higher levels get slight cooling during the day to assist instability to develop.

Let us examine the difference in temperature between the different lightning classes more closely. At 0500 MST major days have warmer temperatures than no-lightning days by about 2.5 to 4 C from the surface up to 700 mb and by smaller amounts at higher levels. Minor days are warmer than no-lightning days by 2 to 3 C up to 700 mb. The maximum difference between classes is found to be in the 850- to 800-mb layer. At 1700 MST the difference between major and minor days becomes more significant at lower

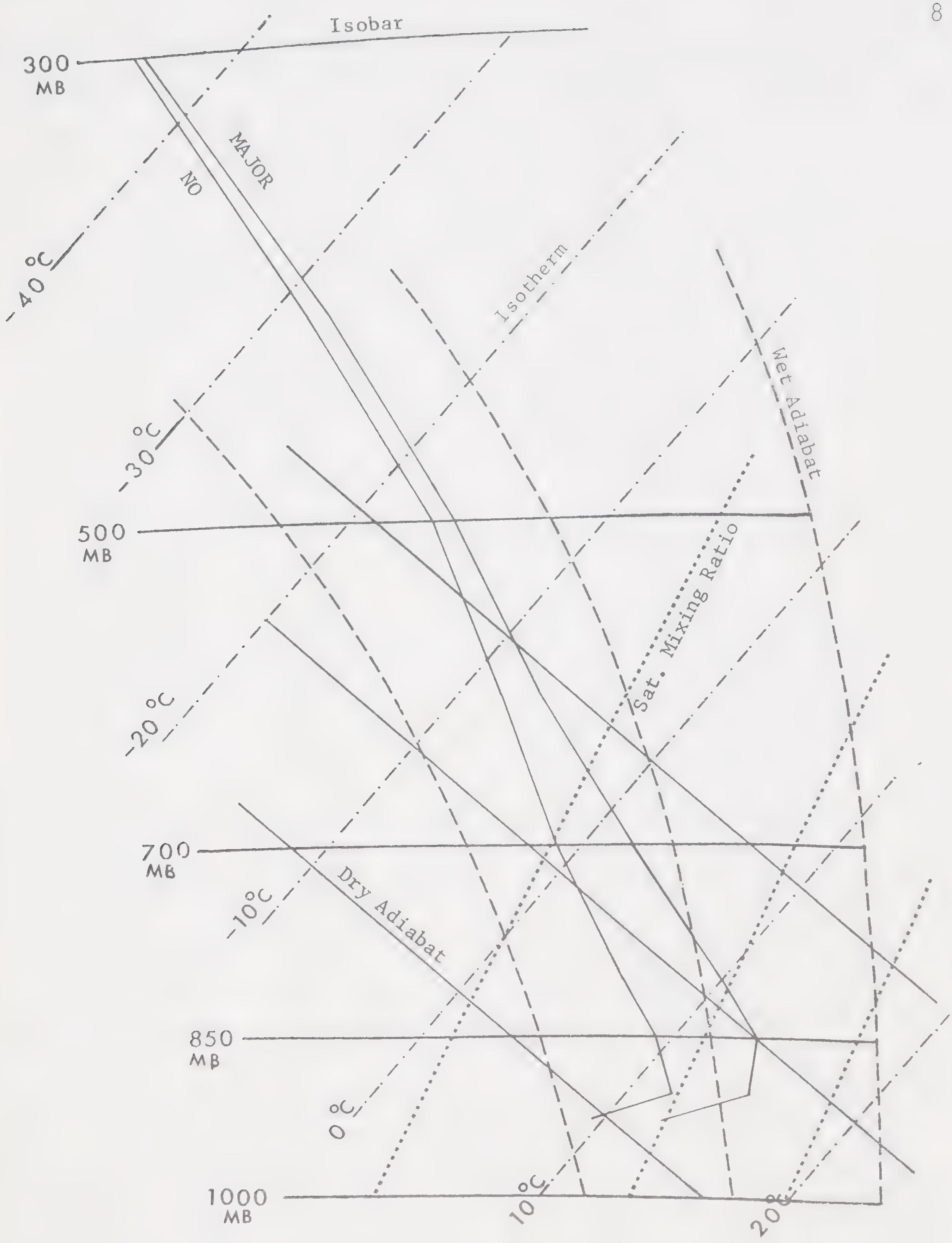

Figure 2.1 - Mean Edmonton soundings for major lightning and no-lightning days at 0500 MST.

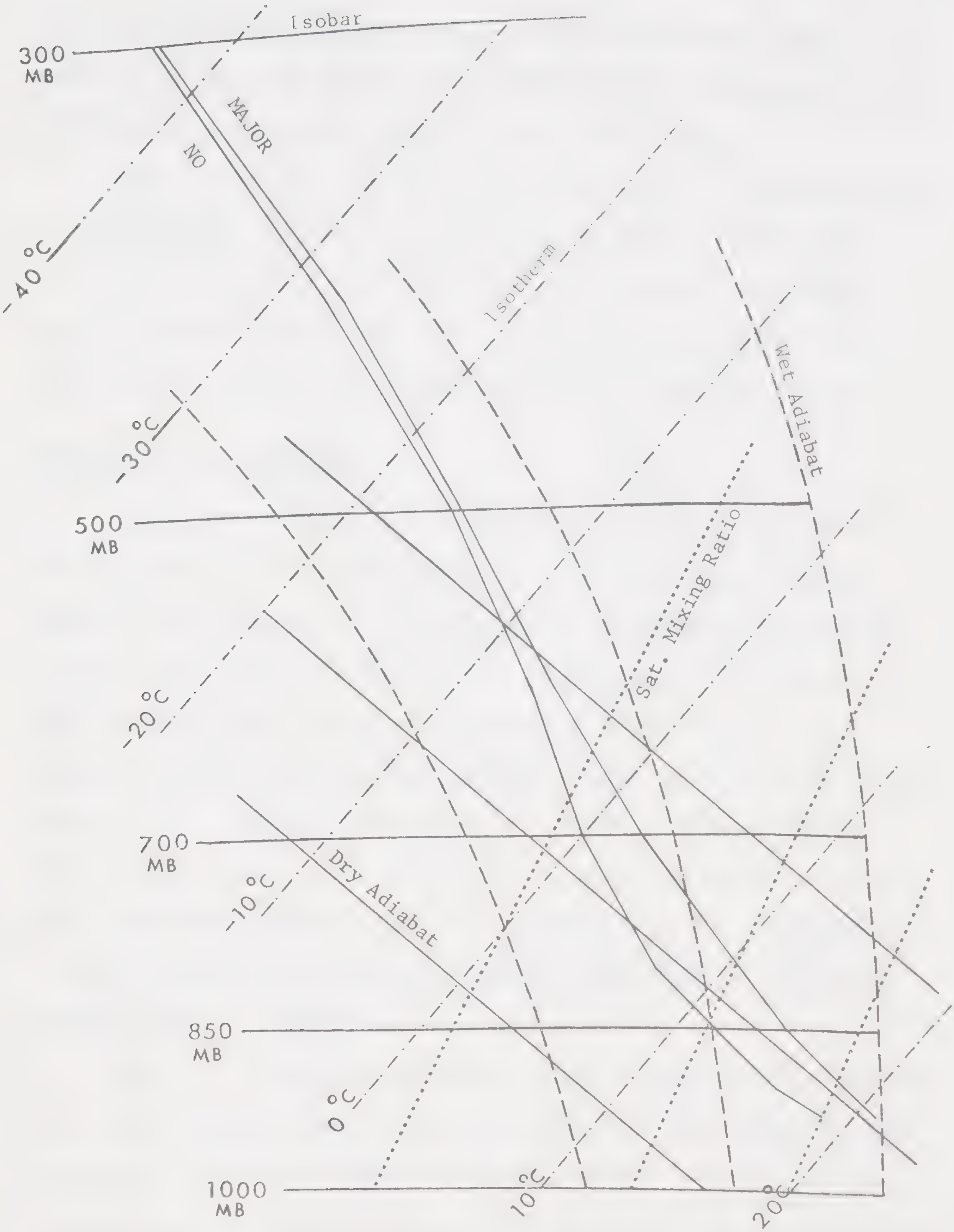

Figure 2.2 - Mean Edmonton soundings for major lightning and no-lightning days at 1700 MST.

levels while that between minor and no-lightning days appears to be less than at 0500 MST. Here the largest difference between classes is found near 800 mb.

From Table 2.1 one notices the inversion of temperature at the surface which exists for all classes at 0500 MST. It is seen to be only 0.6 C stronger on major days than on no-lightning days and one cannot be sure to what extent such a small difference would affect the storm intensity.

THE LOW LEVEL MOISTURE

Large quantities of moisture must be available before the occurence of thunderstorms. When water vapor exists in the lower layers of the atmosphere it helps in warming up the air because of its direct absorption of solar radiation and it then helps in decreasing air density. An increase of water vapor has then the same effect as increasing temperature. When a parcel of air rises, condensation of water vapor will occur above the lifting condensation level and clouds will form. The heat released by the condensation of water vapor represents the major contribution of energy required for a thunderstorm occurrence.

Table 2.2 shows the mean moisture content at the surface, 900-, and 850-mb levels for each class at 0500 and 1700 MST. The table shows that moisture at the lower levels is higher on days of lightning activity than on days free of lightning. An examination of daily values showed that a surface mixing ratio of 8 g/kg or more was found on 65 per cent of the

major lightning days and 59 per cent of the minor days versus 32 per cent of the no-lightning days at 0500 MST.

TABLE 2.2

Mean mixing ratios at the lower levels of the atmosphere for different lightning classes. Values of mixing ratio are given in g/kg.

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
SURFACE	8.0	7.8	6.7	8.6	8.0	6.8
900 mb	7.5	7.4	6.2	7.8	7.2	6.0
850 mb	6.0	6.0	5.0	6.6	6.0	5.2

Similar results were found at 1700 MST. Also by examining the mean mixing ratio throughout the lowest 50-mb layer it is found that the low-level moisture was high on a large portion of lightning days as shown on Table 2.3.

TABLE 2.3

The proportion of major, minor and no-lightning days when mixing ratio at the surface and in the lowest 50 mb was 8 g/kg or more. Proportions are given in percentage.

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
SURFACE	65	59	32	70	57	33
LOWEST 50 mb	48	47	18	53	43	20

The probability of lightning for any specified mixing ratio was determined by the ratio of the number of days

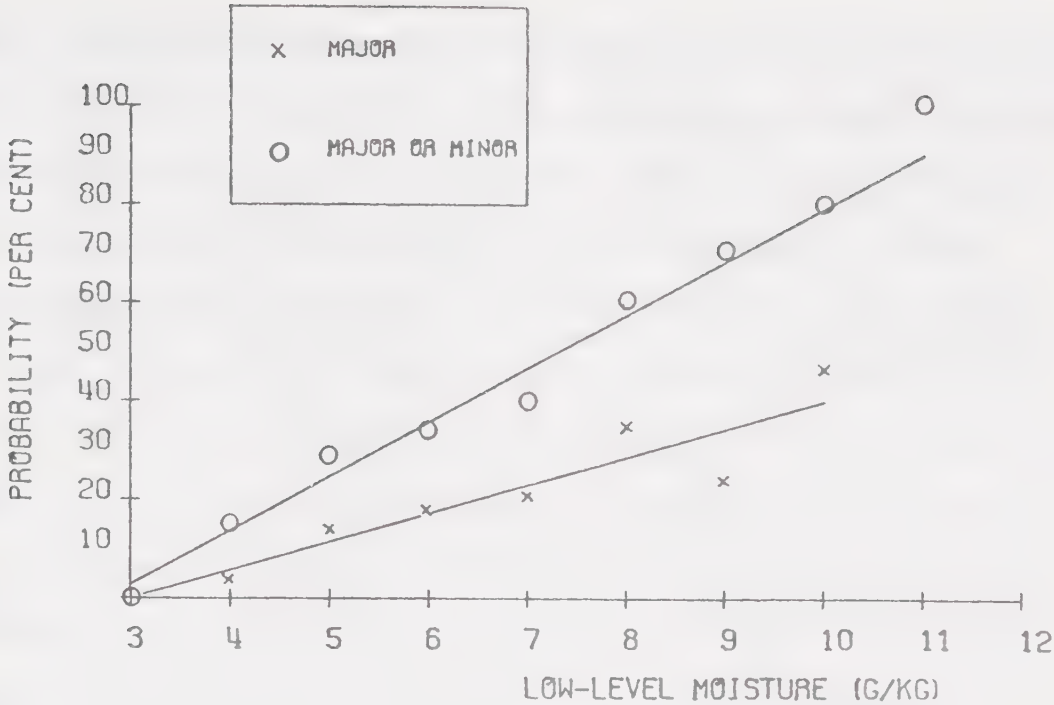

Figure 2.3 - The lowest 50-mb mixing ratio versus the probability of lightning occurrence (0500 MST).

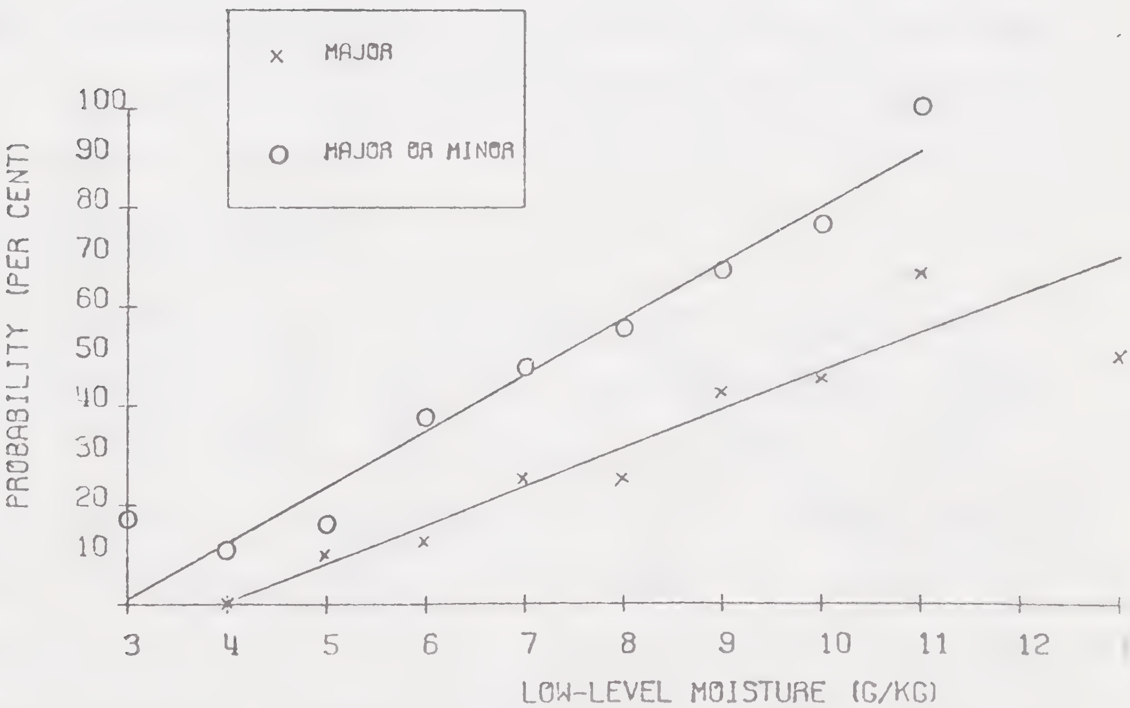

Figure 2.4 - The lowest 50-mb mixing ratio versus the probability of lightning occurrence (1700 MST).

with lightning divided by the total number of days reporting the specific mixing ratio. The resulting probabilities at different mixing ratio values were then used to determine a linear relationship between the mixing ratio and the probability of lightning occurrence by the least squares method. Figures 2.3 and 2.4 show the mixing ratio of the lowest 50-mb layer versus the probability of lightning for 0500 and 1700 MST respectively. From the two figures one can realize that either figure may be used to give the probability of lightning occurrence at each given mixing ratio. In other words, given the 0500 MST mixing ratio averaged over the lowest 50 mb one can use Figure 2.3 to predict whether the day will be a lightning day or not. The only noticeable difference between the two figures is that the probability of major lightning starts from zero at 3 g/kg mixing ratio at 0500 MST while it starts from zero at 4 g/kg at 1700 MST.

THE SURFACE PRESSURE

A large number of lightning storms accompany low-pressure systems and reach their maximum intensity along cold or warm fronts. The decrease in surface pressure has always been an indication of a cyclone moving into the area. The surface pressure may be used as a restrictive parameter because it has been noticed that the incidence of severe storms is sharply reduced as the surface pressure rises above a certain value although other parameters may be present in strength and number.

Table 2.4 gives the mean station pressure at Edmonton Stony Plain (766 m above MSL), standard deviation, and range of values for the different lightning classes.

TABLE 2.4

Mean station pressure (millibars) at Edmonton Stony Plain (766 m) according to thunderstorm occurrence.

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
Mean sur. press.	924.3	923.2	926.0	922.8	922.7	925.7
Standard dev.	4.4	5.4	5.3	4.7	5.3	5.2
Minimum	915	911	913	912	908	909
Maximum	934	938	939	933	937	939

Lightning days reported a lower mean surface pressure than days free of lightning activity. However the range of values, particularly for minor days, seems to be nearly the same as for no-lightning days. Obtained from a frequency distribution of the actual station pressures, Table 2.5 gives the percentage portion of lightning and no-lightning days that reported a value of 924-mb or less and a value of 930-mb or more. From the table it can be seen that surface pressure has some significance in predicting lightning. It can also be observed from Tables 2.4 and 2.5 that minor lightning occurs at lower and higher surface pressures than major lightning. This would suggest that surface pressure as a forecasting parameter is less important on minor days

than on major days.

TABLE 2.5

Proportion of days having a station pressure of 924 mb or less and of days having 930 mb or more for each lightning class (per cent).

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
924 or less	53	63	40	67	66	42
930 or more	13	18	35	13	12	30

The daily station pressure represented by the mean of 0500 and 1700 MST observations at Edmonton Stony Plain (766 m) was used to form a probability distribution of the incidence of either major or minor lightning. The linear relationship between the station pressure in millibars and the probability in per cent is shown on Figure 2.5. At a Stony Plain station pressure of 915 mb or less, the probability of a lightning day is more than 70 per cent without regard to other indices. The figure also shows a probability of 10 per cent or less that lightning occurs when the mean Stony Plain station pressure for the day is 940 mb. In fact, lightning was not observed when the pressure was above 936 mb.

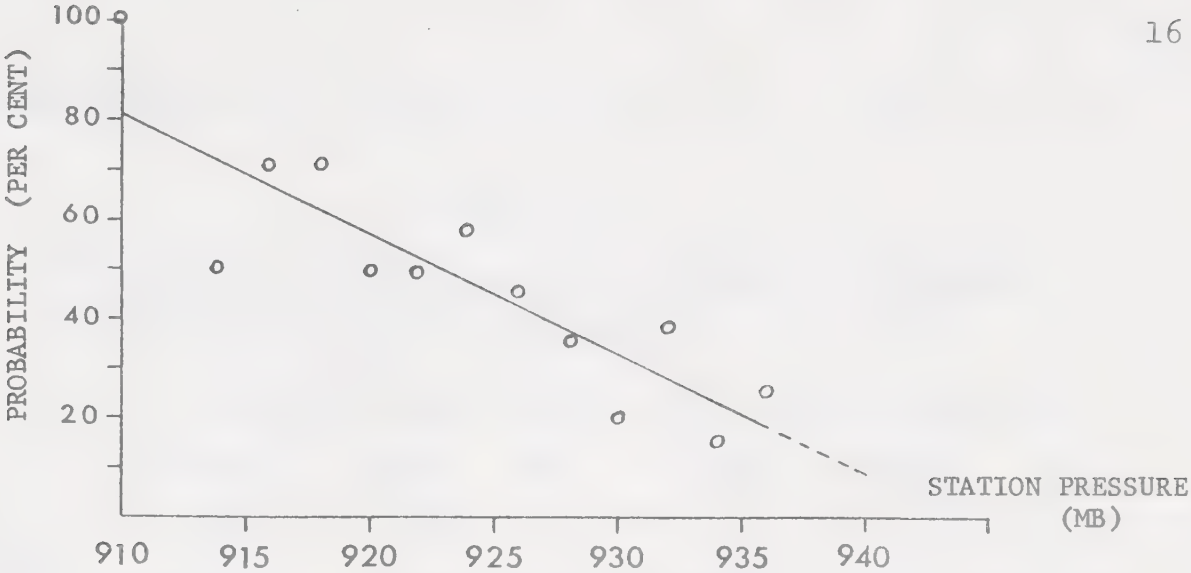

Figure 2.5 - The mean station pressure for the day versus the probability of having either major or minor lightning.

THE 12-HOUR CHANGE IN SURFACE PRESSURE

This parameter reliably indicates major changes or trends in the surface pressure pattern and also reflects important changes aloft. If it would be possible to study the 12-hour fall in surface pressure over an area, this parameter would have been useful in providing clues to the probable areas of maximum low-level convergence and changes in the low-level wind field as well as aiding in predicting the rate of change of low-level heat and moisture. In most productive situations it does appear that pressure falls over a wide-spread area are less important than a pattern of more concentrated falls (Miller, 1967). In the present study we are dealing with only one station and it is the purpose to detect the relationship between the 12-hour change in station pressure and lightning occurrence.

Table 2.6 gives the mean, standard deviation, and range of values for the 12-hour change in surface pressure at

Stony Plain.

TABLE 2.6

The 12-hour change in surface pressure (millibars) for different lightning classes.

	1700 MST to 0500 MST			0500 MST to 1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
Mean	-0.5	-0.4	1.3	-1.5	-0.4	-0.2
Std. dev.	2.9	3.1	3.0	2.5	2.9	3.1
Minimum	-8	-8	-9	-7	-9	-10
Maximum	5	8	13	6	7	10

From the table it is clear that major lightning is associated with the largest mean rate of fall in surface pressure and the smallest range of values compared to other classes. As a result of Table 2.6 it can be said that major lightning days, on the average, are associated with a 12-hour fall in surface pressure of 0.5 mb at 0500 MST followed by another fall of 1.5 mb at 1700 MST. Minor days, on the average, are associated with a 12-hour fall of 0.4 mb at 0500 MST followed by another fall of 0.4 mb at 1700 MST. No-lightning days, on the other hand, are characterized by a 12-hour rise in surface pressure of 1.3 mb at 0500 MST followed by a small change, a fall of 0.2 mb, at 1700 MST.

The frequency distribution of the 12-hour change in surface pressure also shows a distinction between lightning and no-lightning days. Table 2.7 shows the proportion in per cent of days that reported a 12-hour fall in surface

pressure and that reported a rise of 3 mb or more.

TABLE 2.7

The proportion of days which reported a pressure fall or rise in the preceding 12 hours (per cent).

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
FALL	48	52	24	66	52	47
Rise of 3 mb or more	15	22	34	7	15	17

From the table it is seen that a larger proportion of lightning days is characterized by a 12-hour fall in surface pressure while a smaller proportion of lightning days reported a pressure rise. The rate of fall increases, in general, during the day because of the effect of diurnal variation on surface pressure. This effect is felt more on the days free of lightning activity. On major and minor days when other factors such as the movement of low-pressure and frontal systems become more important the diurnal variation has less significance.

The 12-hour change in surface pressure has some correlation with other parameters discussed before. The correlation coefficients between the 12-hour change in surface pressure on one hand and the actual surface pressure, the surface mixing ratio , and the lowest 50-mb mixing ratio on the other hand for 0500 and 1700 MST are given in Table 2.8.

TABLE 2.8

The correlation coefficient between the 12-hour change in surface pressure and other stability parameters.

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
Actual sur. press.	0.37	0.40	0.18	0.38	0.16	0.24
Sur. mixing ratio	-.21	-.23	-.14	-.20	-.18	-.07
Lowest 50-mb mixing ratio	-.29	-.23	-.19	-.24	-.22	-.09

Although the coefficients are fairly small, there is a distinction between lightning and no-lightning days. The absolute values of the coefficients are always greater on lightning days. The best correlation is found, in general, on major days with a small increase over that for minor days. The only noticeable exception is found at 1700 MST between the 12-hour change in surface pressure and the actual surface pressure where the correlation is minimum for minor days while it was maximum at 0500 MST. Table 2.8 provides further evidence that on lightning days the 12-hour fall in surface pressure is more often accompanied by a decrease in actual surface pressure and increase in low-level moisture than on the days free of lightning activity. This result is confirmed by the fact that low-pressure systems are usually associated with high moisture content.

The probability distributions between the 12-hour change in surface pressure and the occurrence of lightning for 0500 and 1700 MST are shown on Figures 2.6 and 2.7 respectively. Notice that the difference between the 0500 MST and 1700 MST probability distributions for major lightning, represented by the lower lines, is very small. In any case if the 12-hour change in surface pressure is positive (i.e. rising pressure), the probability of having a major day is less than 25 per cent, and if a fall of 8 mb occurs the probability will increase to about 45 per cent. The upper line in each of Figures 2.6 and 2.7 represents the probability of having a day of either major or minor lightning. As seen before on Table 2.7, the 12-hour change in surface pressure is not a reliable parameter at 1700 MST for the incidence of minor lightning. The upper line of Figure 2.7 is much different from that for 0500 MST. Moreover, if the upper line of Figure 2.7 is extrapolated downward, it will show a probability of minor lightning at values of large 12-hour pressure rises which are not encountered in practice.

Figure 2.6 may be used as a forecasting tool. According to this figure, a 12-hour pressure fall of 1 mb or more at 0500 MST gives a probability of more than 50 per cent that the day will be a lightning day (major or minor), while a rise of 4 mb or more at 0500 MST will reduce the probability to less than 30 per cent.

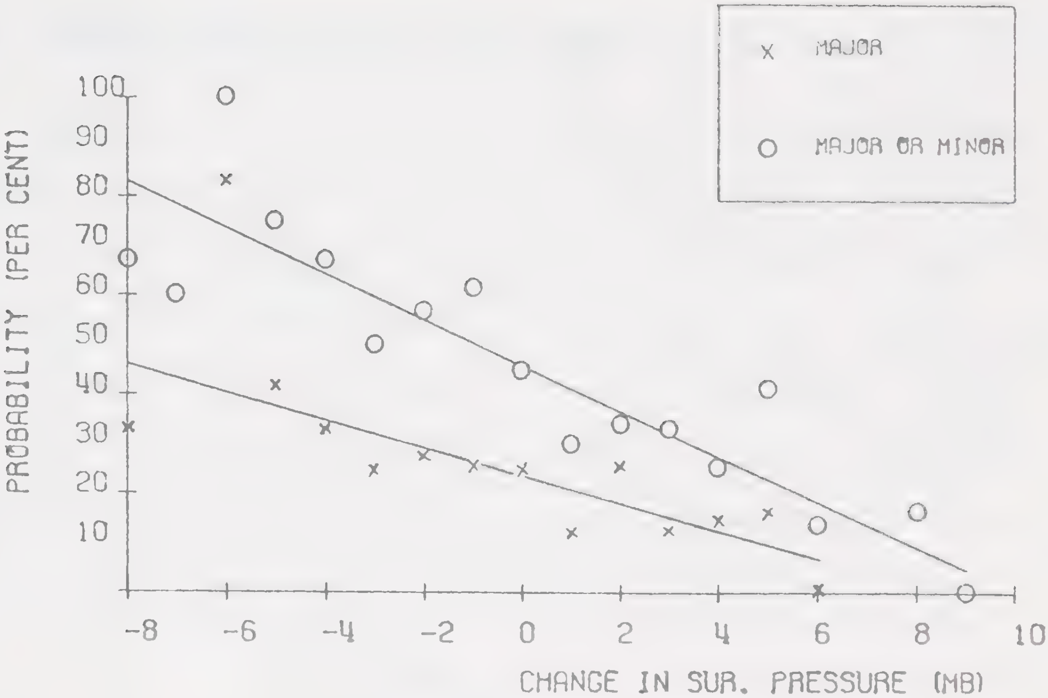

Figure 2.6 - The 12-hour change in surface pressure versus the probability of lightning occurrence (0500 MST).

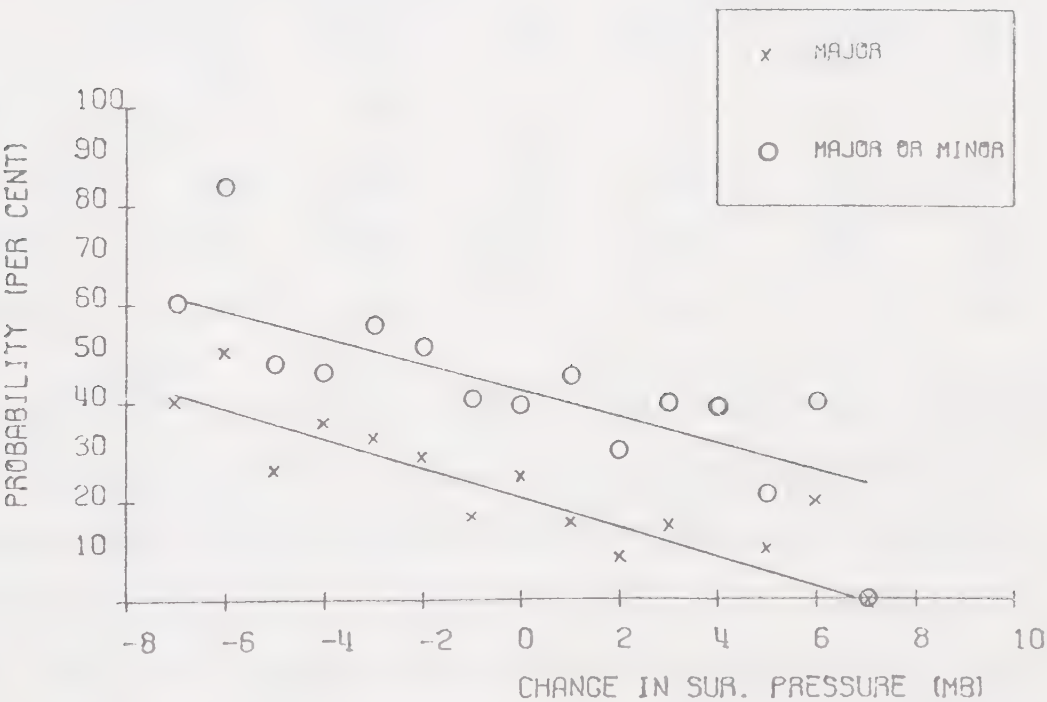

Figure 2.7 - The 12-hour change in surface pressure versus the probability of lightning occurrence (1700 MST).

THE 12-HOUR CHANGE IN 500-MB HEIGHT

Height falls at 500 mb provide the forecaster with valuable clues as to the location and movement of short- and long-wave troughs in the middle troposphere. This parameter in association with the temperature changes at 500 mb is closely related to the 500-mb vorticity field.

The mean 12-hour change in 500-mb height, standard deviation, and range of values at 0500 and 1700 MST are presented in Table 2.9 for different lightning classes.

TABLE 2.9

Mean values of the 12-hour change in 500-mb height (meters) classified according to thunderstorm occurrence.

	1700 to 0500 MST			0500 to 1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
Mean	-22	-28	-10	6	2	28
Std. dev.	20	30	35	27	34	35
Minimum	-90	-106	-141	-56	-85	-125
Maximum	18	36	99	62	72	118

From the table it is seen that no-lightning days, although characterized by high stability, are associated with an average fall in the 500-mb height of 10 m from 1700 MST of the preceding day to 0500 MST on the day of concern. This fall can be explained by the nocturnal cooling in the lower layer and gives rise to a lower 500-mb level at 0500 MST. During the day diurnal heating and other developments

will cause a 12-hour rise of 28 m in 500-mb height at 1700 MST. On days of lightning activity where instability conditions or upper disturbances must be present, the fall in 500-mb height is large overnight and the rise during the day is small, as shown on Table 2.9.

Major and minor days have relatively smaller range of values. However, this does not necessarily mean that when the 12-hour fall in 500-mb height is very large, the probability of having a lightning day becomes small. Obtained from the frequency distributions, Table 2.10 gives the proportion of days which reported a rise in 500-mb height and a fall of 30 m or more.

TABLE 2.10

The proportion of days which reported a fall or a rise of the 500-mb height during the preceding 12 hours (per cent).

	1700 to 0500 MST			0500 to 1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
Rise	11	12	31	58	53	80
Fall (30 m+)	45	47	30	14	23	8

From the table it can be seen that a large proportion of the no-lightning days occur when the 500-mb level rises while the proportion is small compared to lightning days when the 500-mb level falls by 30 m or more in a 12-hour period. As a result the no-lightning days reporting a very large fall in 500-mb height must be few in number and

they may be characterized by other conditions that inhibit lightning occurrence.

Table 2.11 gives the correlation coefficients between the 12-hour change in 500-mb height on one hand and the 12-hour change in surface pressure, the actual surface pressure, and the low-level moisture on the other hand.

TABLE 2.11

The correlation coefficients between the change in 500-mb height and other stability parameters.

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
12-hour change in surface pressure	.50	.39	.27	.33	.07	.19
Actual sur. press.	.42	.51	.42	.49	.45	.33
Lowest 50-mb mixing ratio	-.33	-.18	-.14	-.29	-.12	.02

From the table, we can generally speak of higher correlations for lightning days than for no-lightning days, although the coefficients are fairly small. At 1700 MST the correlation between the change in 500-mb height and the change in surface pressure is smallest for minor days. A similar result was found in the previous section. The larger coefficients of Table 2.11 are in agreement with the fact that lightning occurrence is usually associated with cyclone movements which produce falls in the 500-mb height and in

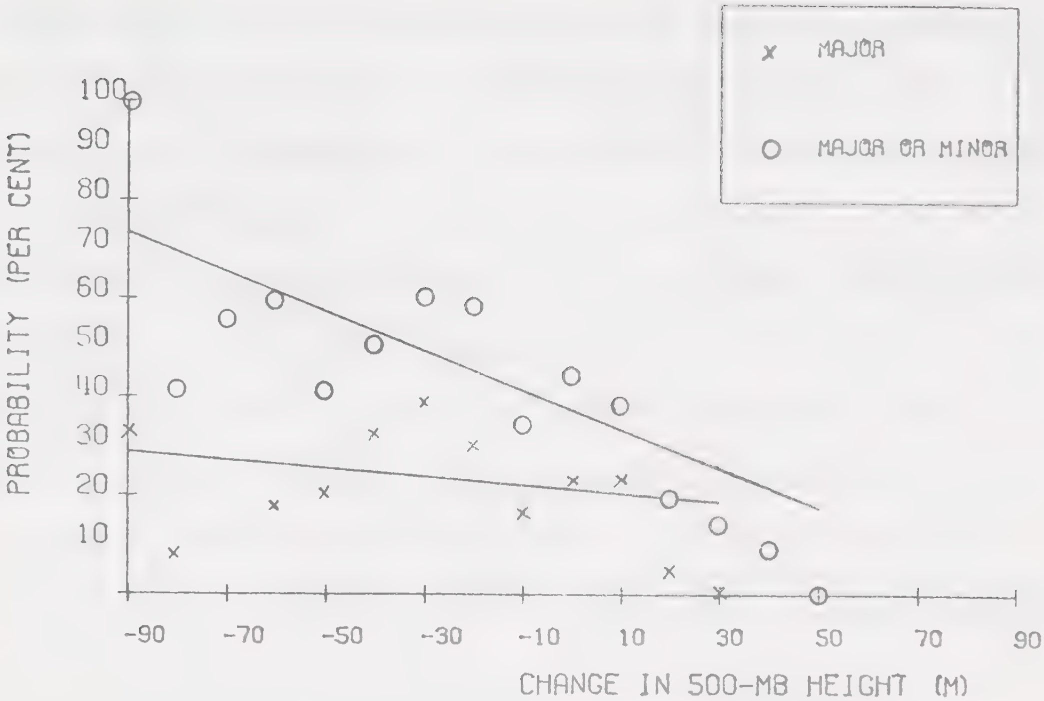

Figure 2.8 - The 12-hour change in 500-mb height versus the probability of lightning occurrence (0500 MST).

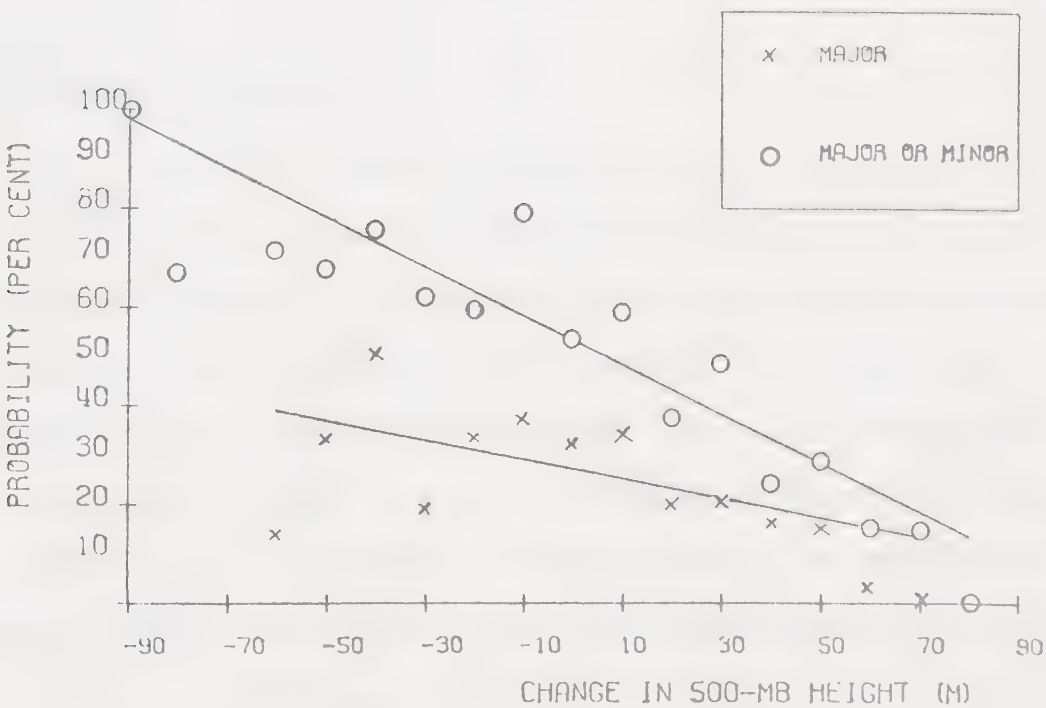

Figure 2.9 - The 12-hour change in 500-mb height versus the probability of lightning occurrence (1700 MST).

surface pressure as well as increasing moisture content.

The 12-hour change in 500-mb height versus the probability of lightning occurrence for 0500 and 1700 MST are shown on Figures 2.8 and 2.9 respectively. For major lightning, which is represented by the lower line in each figure, the slopes are very small and the distribution may fail to give a reliable probability. The upper lines, however, may be useful in forecasting lightning in general. For example, Figure 2.9 shows that with a 12-hour fall of 90 m at 1700 MST, the probability of having a lightning day, major or minor, will be close to 100 per cent regardless of other stability parameters. Also, if a rise of 70 m or more occurs in 500-mb height at 1700 MST, the probability of having a day with lightning activity will be less than 20 per cent.

THE SHOWALTER INDEX

The Showalter index (Showalter, 1953) is one of the best stability indices for studying and forecasting severe weather outbreaks. It employs the 850-mb wet bulb potential temperature and the 500-mb temperature. This index is preferred to one using surface data because it uses data from standard isobaric levels and because the 850-mb data are less subject to diurnal variation than are parameters selected from lower levels. The Showalter index S is given by

$$S = T_{500} - (LT)_{850}$$

where T_{500} is the temperature at the 500-mb level and

$(LT)_{850}$ is the temperature of the 850-mb parcel after it has been lifted (dry-adiabatically and pseudosaturated adiabatically) to the 500-mb level. As the value of S decreases the instability of the air column increases.

The mean values of the Showalter index for major, minor and no-lightning days at 0500 and 1700 MST are shown on Table 2.12.

TABLE 2.12

The mean Showalter index for the different lightning classes.

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
Mean	1.6	2.4	5.0	0.5	1.8	4.2
Std. dev.	2.4	2.3	3.2	2.6	2.1	3.0
Minimum	-6.4	-2.4	-2.4	-10.5	-5.4	-2.4
Maximum	7.6	8.6	15.6	6.3	7.1	16.8

The table shows that lightning days are associated with smaller values of the Showalter index than no-lightning days. Major days are associated with the largest drop in the index from 0500 to 1700 MST. The ranges of values show that this index has a uniform distribution in the sense that the smallest values characterize the major lightning days and the largest values appear on the no-lightning days.

More clearly Table 2.13 shows the proportion of days

in each lightning class that reported a negative Showalter index and that reported a value of +6 or more.

TABLE 2.13

The proportion of days in each lightning class which reported a small and a large Showalter index (per cent).

	0500 MST			1700 MST		
Showalter index	MAJOR	MINOR	NO	MAJOR	MINOR	NO
- 1 or less	17	9	1	32	15	2
+ 6 or more	7	12	38	2	6	31

From the information of the table it becomes clear that the Showalter index best distinguishes between the different classes in both 0500 and 1700 MST observations. This index, however, has irregular correlations with the other stability indices discussed before. For details Table 2.14 gives the correlation coefficients between the Showalter index on one hand and the change in surface pressure, the change in 500-mb height, the actual surface pressure, and the low level moisture on the other hand.

As seen in Table 2.14, the best correlation is found between the Showalter index and the low-level moisture. This is not unexpected because the 850-mb moisture is used in computing the index value. The largest coefficient, although found for major class, is not much higher than for no-lightning class. The best correlation on minor days is found between the Showalter index and the 12-hour change in surface pressure but it is not significantly higher than

for no-lightning days. The correlations between the Showalter index and other indices do not distinguish between lightning classes.

TABLE 2.14

The correlation coefficients between the Showalter index and other stability indices.

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
12-hour change in sur. press.	.18	.27	.26	.21	.31	.25
12-hour change in 500-mb height	.28	.15	.24	-.06	-.08	.04
Actual sur. press.	.16	.29	.27	.08	-.05	.32
Lowest 50-mb mixing ratio	-.61	-.46	-.58	-.50	-.20	-.40

Figures 2.10 and 2.11 show the Showalter index versus the probability of lightning occurrence for 0500 MST and 1700 MST respectively. For small values of Showalter index the two figures give almost the same result while at high Showalter index there is little difference between the 0500 and 1700 MST figures. According to these figures, if the index value is -3 at 0500 or 1700 MST the probability of having a day with major or minor lightning is about 95 per cent without regard to other weather parameters. On the other hand, an index value greater or equal to +6 at 0500 MST will produce a probability of less than 25 per cent

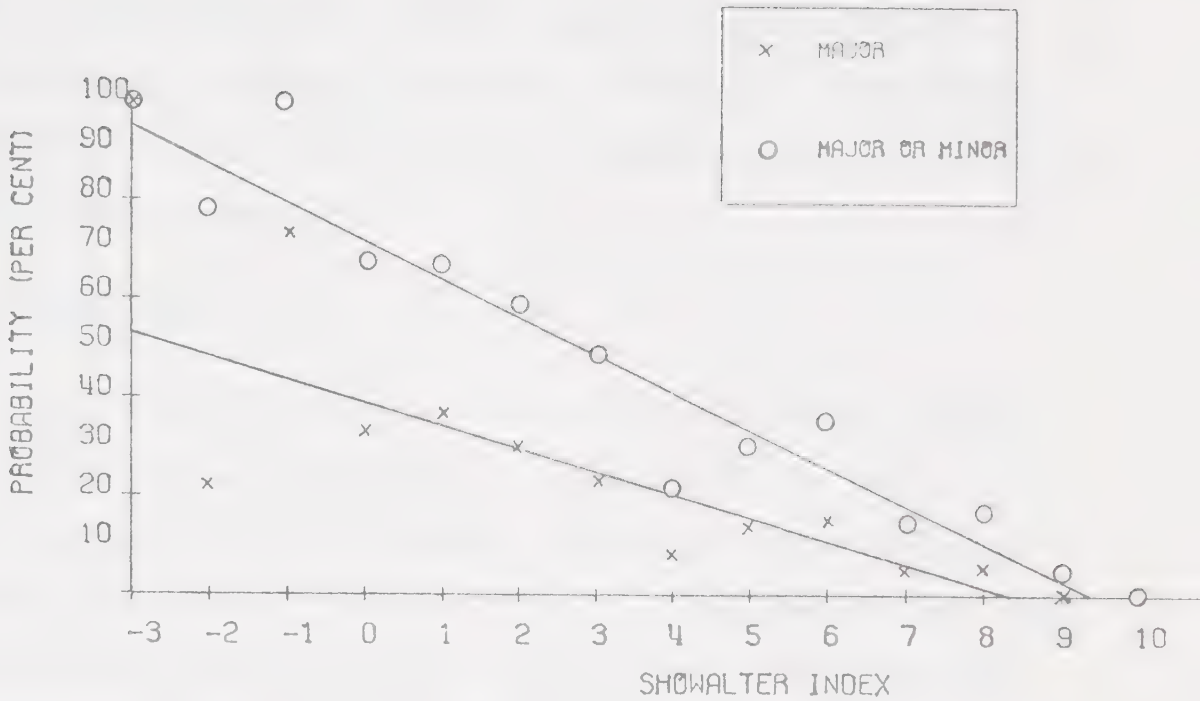

Figure 2.10 - The Showalter index versus the probability of lightning occurrence (0500 MST).

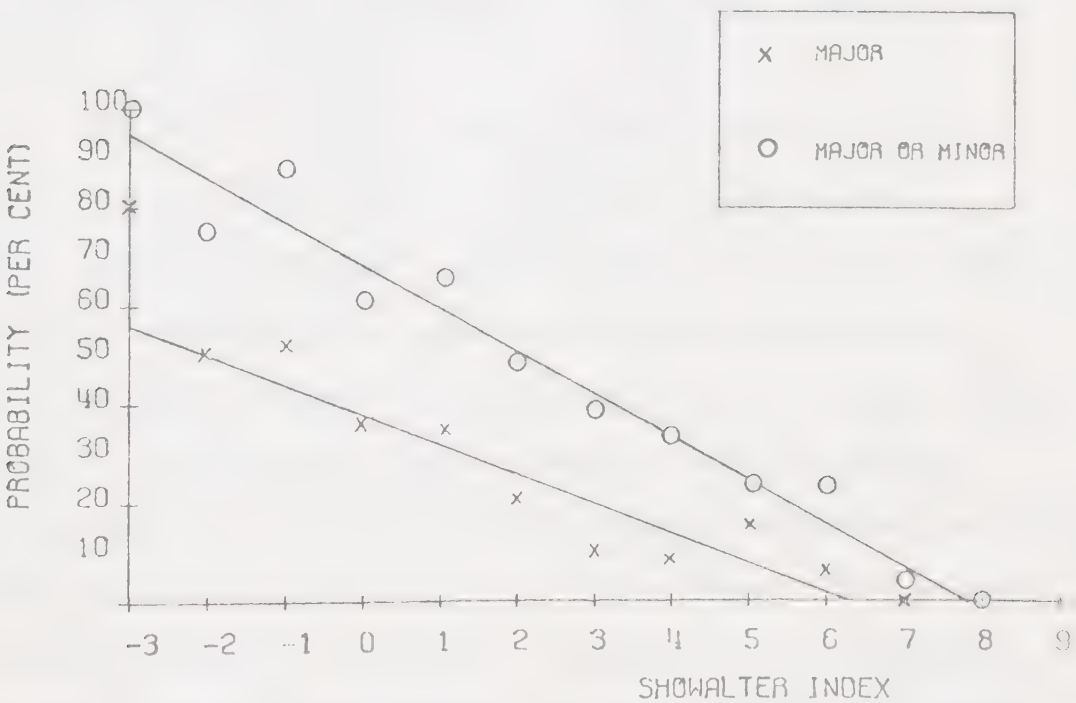

Figure 2.11 - The Showalter index versus the probability of lightning occurrence (1700 MST).

that the day will be a lightning day. The probability reduces to less than 15 per cent if the value of 6 or more is observed at 1700 MST. The two figures may be used as forecasting guides.

THE TOTALS INDEX

The 850-mb level is less subject to diurnal variation and this gives an advantage to using the 850-mb data along with the 500-mb data to produce stability indices and forecasting parameters. Vertical Totals, Cross Totals and Total Totals proved useful in forecasting severe thunderstorms. The Vertical Total is the 500-mb dry-bulb temperature subtracted from the 850-mb dry-bulb temperature. The Cross Total is the 500-mb dry-bulb temperature subtracted from the 850-mb dew-point temperature. The Total Total is the sum of the Vertical Total and Cross Total.

In the United States thunderstorm occurrences are associated with values of the Vertical Total of 26 or more ignoring moisture, except along the coastal areas of the Gulf States where values less than 26 are often associated with thunderstorm activity (Miller, 1967). In the British Isles this value is near 22 and in western Europe is about 28. Because the Vertical Totals are derived without regard to moisture, it is practicable for forecasting for an island, or along the windward side of coastal mountains, or over large bodies of water such as the Great Lakes. To further delineate the potential thunderstorm

areas and probable intensities, the Cross Total data must be analyzed. East of the American Rockies the Cross-Total threshold value of 18 is used as the lower limit for thunderstorms, and a Total Total of 44 is a minimum (Miller, 1967). These values are only guides since terrain and local effects and movements of fronts and pressure centres will occasionally combine to produce thunderstorms. The higher the Vertical Totals in the area of significant Cross Totals, the greater will be the severity and certainty of thunderstorm development. The Total Total appears to be a more reliable single predictor of severe activity in both warm- and cold-air situations. However, Total Totals must be used with careful attention to either the Cross Totals or the low-level moisture, because it is possible to have large Total Totals under adiabatic conditions with little supporting low-level moisture.

It is now the purpose to study the effect of these indices on lightning occurrence in the Whitecourt Forest using the data of Edmonton Stony Plain. Table 2.15 gives the mean, standard deviation, and range of values of each index for the different lightning classes. The table shows that days of lightning activity are associated with larger values of Vertical Total, Cross Total and Total Total than days free of lightning. The table also indicates that in some situations, which must be few in number, major lightning occurs when the Cross Total is fairly small and on some no-lightning days any of the three indices may be fairly large.

TABLE 2.15

The Vertical, Cross, and Total Totals for the different lightning classes.

		0500 MST			1700 MST		
		MAJOR	MINOR	NO	MAJOR	MINOR	NO
VERTICAL TOTAL	Mean	29.4	28.4	26.2	30.1	29.0	27.5
	Std. dev.	2.6	3.1	3.2	[illegible]	[illegible]	3.4
	Minimum	23.5	20.8	[illegible]	22.2	20.5	17.3
	Maximum	37.2	35.8	35.1	35.8	35.5	35.6
CROSS TOTAL	Mean	19.4	19.1	17.7	20.0	19.6	17.2
	Std. dev.	3.4	3.4	3.9	3.1	2.6	3.4
	Minimum	8.9	9.9	4.3	9.4	13.0	3.0
	Maximum	26.7	25.4	24.9	30.7	25.8	26.0
TOTAL TOTAL	Mean	48.8	47.5	43.9	50.2	48.6	44.7
	Std. dev.	4.0	3.9	5.4	4.2	3.6	5.1
	Minimum	38.8	37.0	24.7	40.9	39.3	23.4
	Maximum	58.8	55.1	55.3	66.9	56.1	57.0

The proportions of days in each lightning class which reported small and large index values are given in Tables 2.16, 2.17 and 2.18 for the Vertical, Cross and Total Totals respectively.

TABLE 2.16

Proportion of days having a Vertical Total of 32 or more and of 24 or less (per cent).

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
VT of 32 or more	24	20	7	42	29	15
VT of 24 or less	5	12	35	4	10	21

TABLE 2.17

Proportion of days having a Cross Total of 22 or more and of 14 or less (per cent).

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
CT of 22 or more	33	32	24	39	27	13
CT of 14 or less	9	14	26	4	5	25

TABLE 2.18

Proportion of days having a Total Total of 52 or more and of 44 or less (per cent).

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
TT of 52 or more	29	22	7	40	26	9
TT of 44 or less	14	31	52	12	12	48

As a result of the information given in the three tables, it is seen that lightning days are characterized by the larger values of the three indices. It may be suggested that the few no-lightning days which reported large Vertical, Cross or Total Totals are either characterized by other stability conditions or being classified in the wrong spot.

The Vertical Total and Cross Total are highly correlated with the Showalter index. The Total Total is obviously correlated with each of the other three. The best correlation was found between the Total Total and the Showalter index because both of them measure basically the same thing. No differences of any significance were found among the lightning classes as far as the correlation coefficients between these indices are concerned. Table 2.19 shows the correlations between the Total Total on one hand and the Showalter, Vertical Total and Cross Total on the other hand.

TABLE 2.19

The correlation coefficients between the Total Total index and other stability indices.

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
Showalter	-.93	-.92	-.95	-.94	-.91	-.94
Vertical Total	.54	.55	.71	.68	.71	.75
Cross Total	.78	.65	.82	.75	.57	.75

In general, it is seen from the table that the coefficients are slightly greater for the no-lightning class. This may have resulted from the larger number of days present in this class.

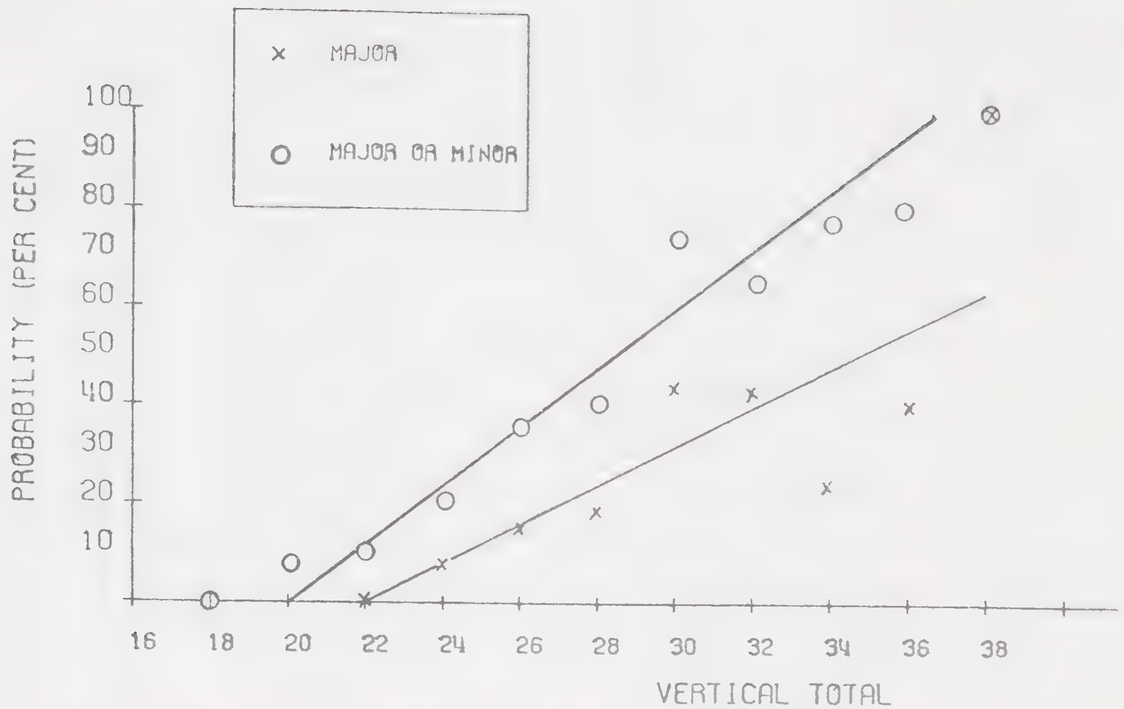

Figure 2.12 - The Vertical Total versus the probability of lightning occurrence (0500 MST).

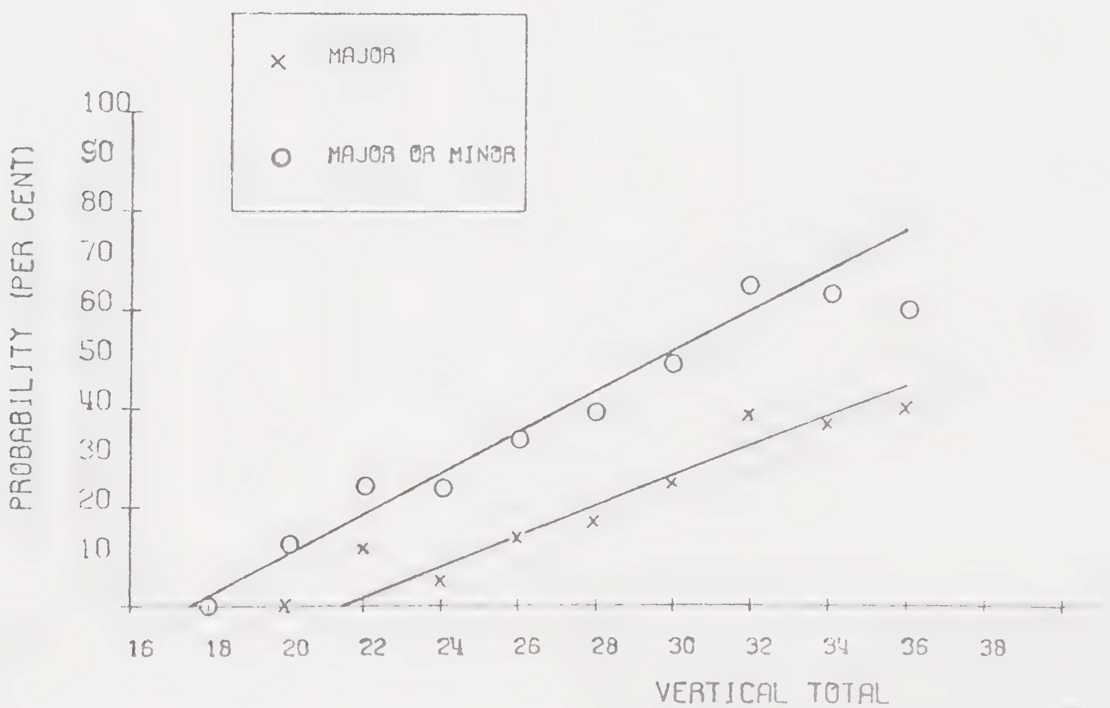

Figure 2.13 - The Vertical Total versus the probability of lightning occurrence (1700 MST).

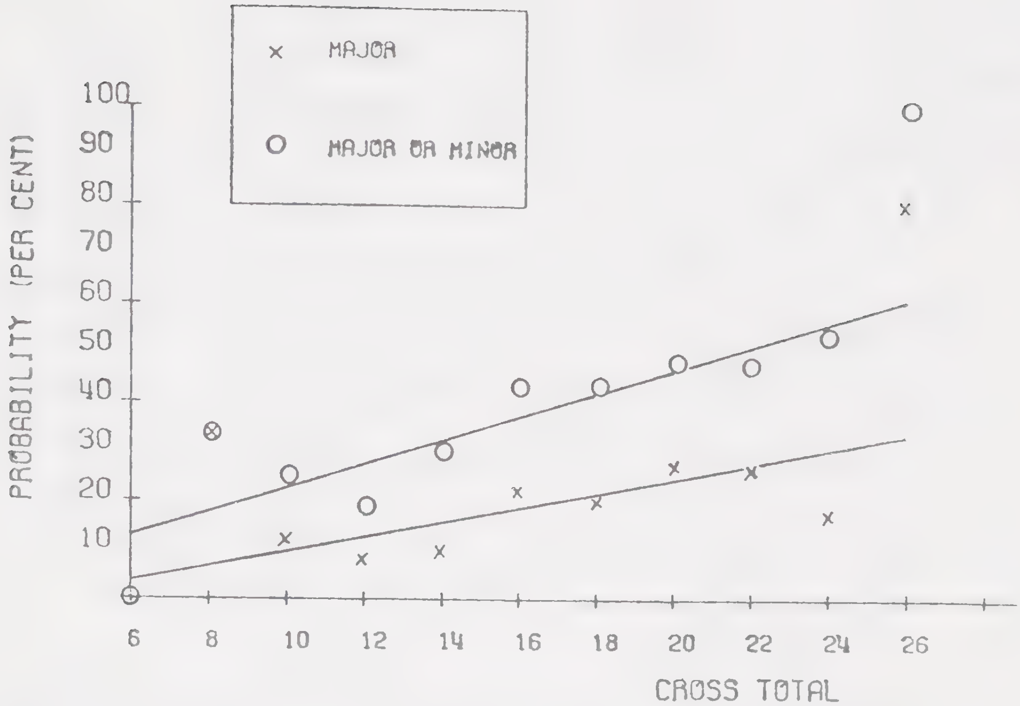

Figure 2.14 - The Cross Total versus the probability of lightning occurrence (0500 MST).

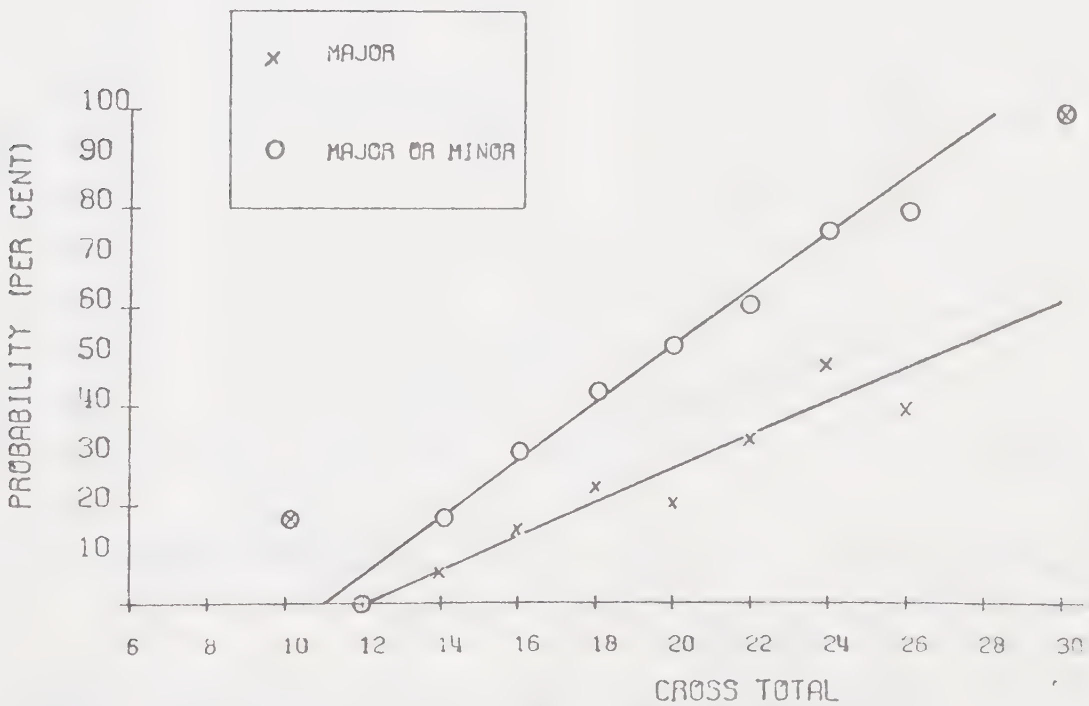

Figure 2.15 - The Cross Total versus the probability of lightning occurrence (1700 MST).

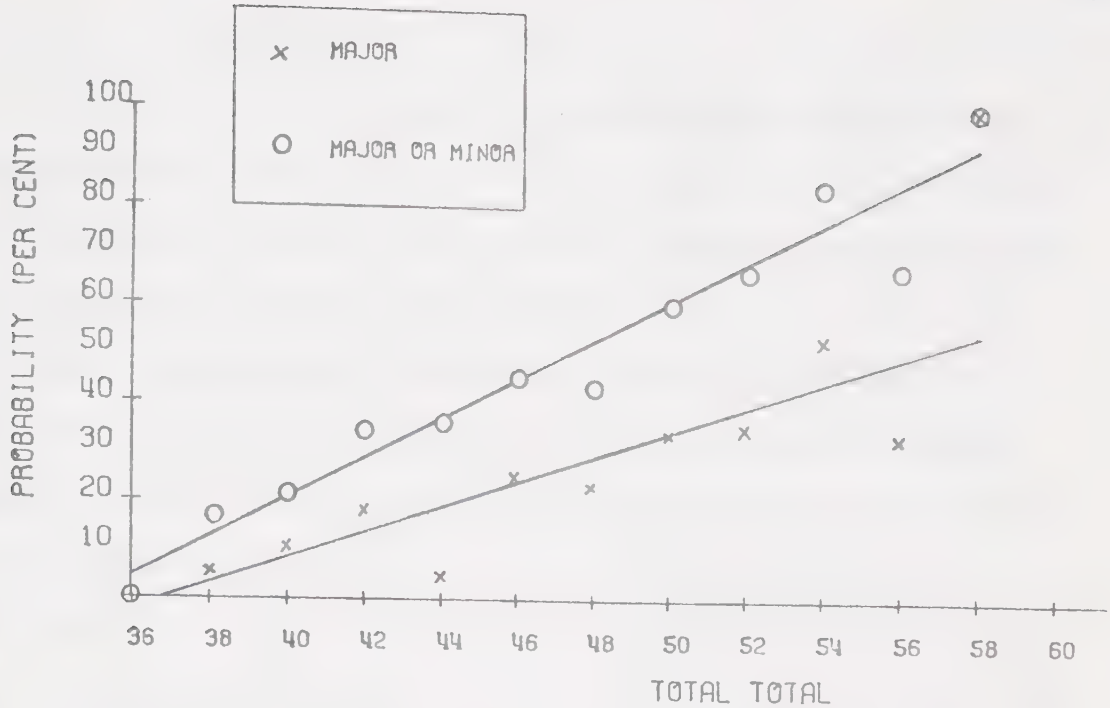

Figure 2.16 - The Total Total versus the probability of lightning occurrence (0500 MST).

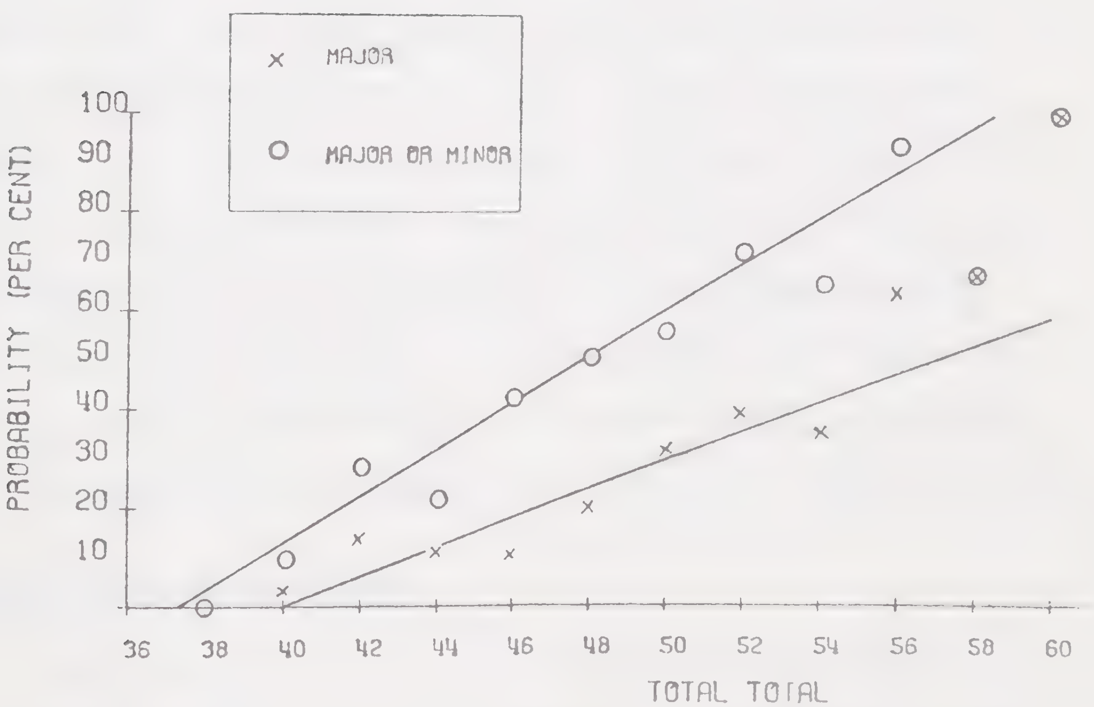

Figure 2.17 - The Total Total versus the probability of lightning occurrence (1700 MST).

The relationship between the Vertical Total and the probability of lightning is shown on Figures 2.12 and 2.13 for 0500 and 1700 MST respectively. Figures 2.14 and 2.15 show the Cross Total versus the probability for 0500 and 1700 MST respectively. Figures 2.16 and 2.17 show the Total Total versus the probability for 0500 and 1700 MST respectively. The threshold values at 0500 MST for having a major lightning day are 22 for the Vertical Total and 37 for the Total Total. No reliable value for the Cross Total can be given from Figure 2.14 as a threshold for occurrence of lightning. At 1700 MST the Vertical and Cross Totals show probability distributions of lightning occurrence different from 0500 MST. However, the Total Total shows almost the same probability distribution for 0500 and 1700 MST observations except for small values of the index. Figure 2.13 shows that a Vertical Total of 36 at 1700 MST gives a probability about 75 per cent that the day will be a lightning day without regard to other indices. The corresponding values for the Cross Total and Total Total are 24 and 53 respectively. Different results using the Total indices may be explained by the small sample of data.

THE WET BULB ZERO HEIGHT

The height of the Wet Bulb Zero above the earth's surface is assumed to be the height of the lowest intersection between the 0 C isotherm and the wet-bulb temperature

profile of the environment on a tephigram. In many instances when thunderstorms form, there is little ground damage. Careful examination of many of these situations indicates that the Wet Bulb Zero height above the earth's surface may be the best single index for descriminating the cases in which the damaging phenomena such as hail and strong winds affect the ground (Miller, 1967). A chart having the isolines of Wet Bulb Zero height provides an effective separation of areas where severe phenomena such as large hail reach the ground from areas where they do not. Thus, the line of separation offers the forecaster a useful tool for determining the most probable extent of severe-weather phenomena at the earth's surface, when other criteria predict they are likely to occur.

When a large cloud develops upwards and penetrates colder regions of the atmosphere, the cloud droplets start freezing. The latent heat liberated on solidification warms the surrounding air and gives it further buoyancy, causing the cloud to expand still farther upwards. The contribution of latent heat of freezing to the buoyancy can thus be active in a large vertical extent of the cloud. In hail studies, it was found that when Wet Bulb Zero heights were above 11,000 feet or below 7,000 feet above the terrain, the frequency and size of hail diminished rapidly (Miller, 19 It is the purpose now to find out if a relationship exists between the height of Wet Bulb Zero at Edmonton when lightning was observed in the Whitecourt Forest. Table

2.20 gives the mean height of Wet Bulb Zero, standard deviation, and range of values at 0500 and 1700 MST for each lightning class.

TABLE 2.20

Heights of Wet Bulb Zero above Mean Sea Level (decameters) classified according to thunderstorm occurrence.

	0500 MST			1700 MST		
	MAJOR	MINOR	NO	MAJOR	MINOR	NO
Mean height	335	322	287	342	323	309
Std. dev.	51	51	60	48	51	67
Minimum	229	226	122	241	239	103
Maximum	436	430	454	435	459	485

The table shows that lightning days, on the average, are associated with higher Wet Bulb Zero than no-lightning days. However, no-lightning class was characterized by the largest range of values. Heights as low as 1220 m and as high as 4540 m were observed at 0500 MST on no-lightning days while a smaller range was reported on lightning days. Similar results are also found at 1700 MST (see Table 2.20). It can then be said that although the Wet Bulb Zero, on the average, was higher on lightning days, lightning activity was not observed when the Wet Bulb Zero level rises above a certain height. However, the no-lightning situations with such very high Wet Bulb Zero were very few in number and no conclusive result can be given here. It becomes rather clear that low Wet Bulb Zero heights are infrequent on days of

lightning activity. From a frequency distribution of 0500 MST observations it was found that 13 per cent of major and 18 per cent of minor days reporting a Wet Bulb Zero height of 2600 m or less versus 41 per cent of the no-lightning days. At 1700 MST the corresponding figures were 9 per cent for major class, 16 per cent for minor class and 29 per cent for the no-lightning class. From the information of Table 2.20 it can be seen that more than 70 per cent of lightning days (major or minor) reported a Wet Bulb Zero height between 2700 m and 3900 m above MSL in any of 0500 or 1700 MST observations.

MAXIMUM TEMPERATURE ON SURFACE

Strong heating at the earth's surface assists instability to develop. It helps in lifting the air parcel and controlling the transport of moisture to higher levels. In some situations where a strong inversion exists near the surface prior to a thunderstorm occurrence, strong surface heating works as the breaking mechanism and gives rise to air-mass thunderstorms. In other situations, however, the passage of cold fronts will be the controlling mechanism and frontal thunderstorms may develop if the warm air is convectively unstable. No strong surface heating is required for such situations.

The daily maximum surface temperature at Whitecourt was used in an attempt to find a correlation with lightning occurrence in the Whitecourt Forest. Although the mean

maximum temperature was higher on lightning days than on no-lightning days, the distributions of the daily maximum temperature did not seem to be significantly different from one class to another.

The relationship between the maximum surface temperature and the probability of lightning is shown on Figure 2.18. The slopes of the lines are small, showing that this index is a poor indicator for the incidence of lightning and it cannot be used alone as a unique predictor. However, a careful analysis of other atmospheric parameters along with the maximum temperature on surface can produce a more successful forecast of lightning.

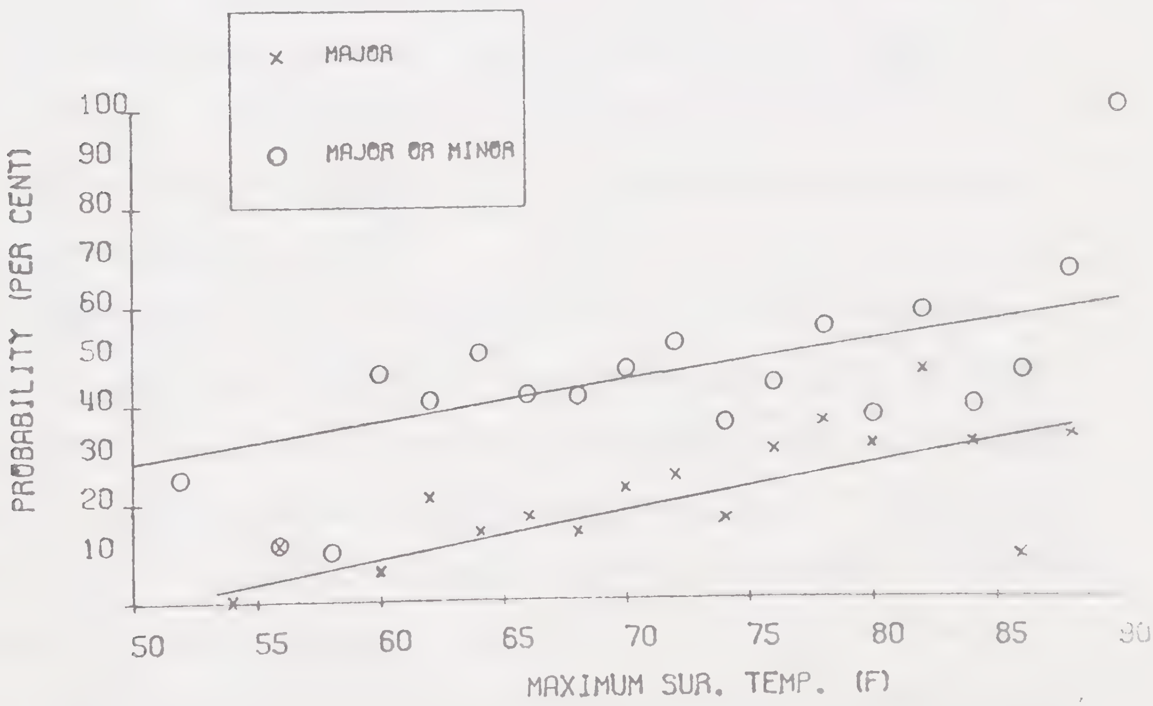

Figure 2.18 - The daily maximum surface temperature versus the probability of lightning occurrence.

CHAPTER THREE

THE CORRELATION BETWEEN UPPER-WIND PATTERN AND LIGHTNING OCCURRENCE

Severe thunderstorms tend to occur in localities where there is a strong shear between the winds in the lower and upper troposphere. It is commonly observed that small cumulus clouds, when subjected to appreciable shear, have their tops blown off their bases. Recent research has disclosed that large storms are actually invigorated by the presence of shear. In a sheared environment the storm, moving at some particular velocity, is in motion relative to the winds at different levels, and thus is in effect moving through the air mass. Weickmann (1953) pointed this out as a distinguishing feature of storms that persist for a long time, by virtue of their being able to sweep up moist air as they migrate through it.

As observed by Fulks (1951) a strong inversion above a surface layer of moist air plays an important role in contributing to the severity of convective disturbances. Beebe (1958) has shown, on the contrary, that inversions are not present when and where tornadoes and thunderstorms occur. Beebe and Bates (1955) have indicated that one of the principal agents in their removal is organized vertical motion. Lifting results in adiabatic cooling of the dry air above the inversion with a simultaneous increase in depth of the moist layer. If, as is likely, the moist air

reaches saturation during this process, it will cool at the lesser moist adiabatic rate, being free to penetrate to high levels once the inversion is removed. In general, no such inversions were observed on lightning days in the present study. Only a weak inversion at the surface was found at 0500 MST on lightning days. No-lightning days have also reported a similar inversion but a little weaker (see Figure 2.1).

The organized vertical motions are, in general, connected with synoptic scale low-pressure systems. Downstream from troughs in the upper troposphere, there is generally horizontal mass divergence in the upper troposphere, coupled with convergence in the lower troposphere. Linked with this, the broadscale upward motions in the middle troposphere commonly have magnitudes of 5 to 10 cm/sec (Newton, 1967). Acting over a period of 6 to 12 hours, such vertical motions provide a net lifting of 1 to 2 km, which is sufficient to eliminate even a strong inversion.

The upper-level divergence is associated with the variation of vorticity along the current and with the strength of the upper winds. For this reason, vertical motions tend to be strongest near the jet stream in upper levels. The low-level jet stream is the region where moist air and heat are advected most rapidly to an area where, as a consequence, convective instability is likely to be generated first. These two factors largely account for the

tendency for severe convection to take place first near the intersection of a low-level and an upper-level jet stream.

The onset of convection may be triggered by the gradual upward motions mentioned above, but often other factors come into play. Lifting by the cold front as it sweeps into the edge of the tongue of unstable moist air may be the decisive mechanism. On other occasions, lifting at the warm front or over a cold dome residual from earlier thunderstorms may be instrumental. In all cases, diurnal heating or cooling must be taken into account. Surface heating may be sufficient in itself to cause buoyant air to rise to the condensation level and, in the absence of an inhibiting stable layer, to set off deep convection. Even when dynamical lifting mechanisms are available, solar heating is important because less lifting is needed to set off convection when heat has been added in lower levels. The importance of insolation is attested by the pronounced preference for convective phenomena to occur in mid and late afternoon.

The results of a study of the wind pattern of Edmonton at the standard pressure levels 850, 700, 500 and 300 mb and the interrelations between these levels for each of the lightning classes of Whitecourt Forest is now presented.

Figure 3.1 shows the proportion of days (in per cent) which reported an 850-mb wind from the different directions for major, minor and no-lightning days at 0500 and 1700 MST.

The proportion is given by the number of winds of a certain direction of one class divided by the total number of days in this class. For example, 10 per cent of the major lightning days reported a wind from the north at 850-mb level at 0500 MST. Figures 3.2, 3.3 and 3.4 show the proportions for the 700-, 500- and 300-mb levels respectively.

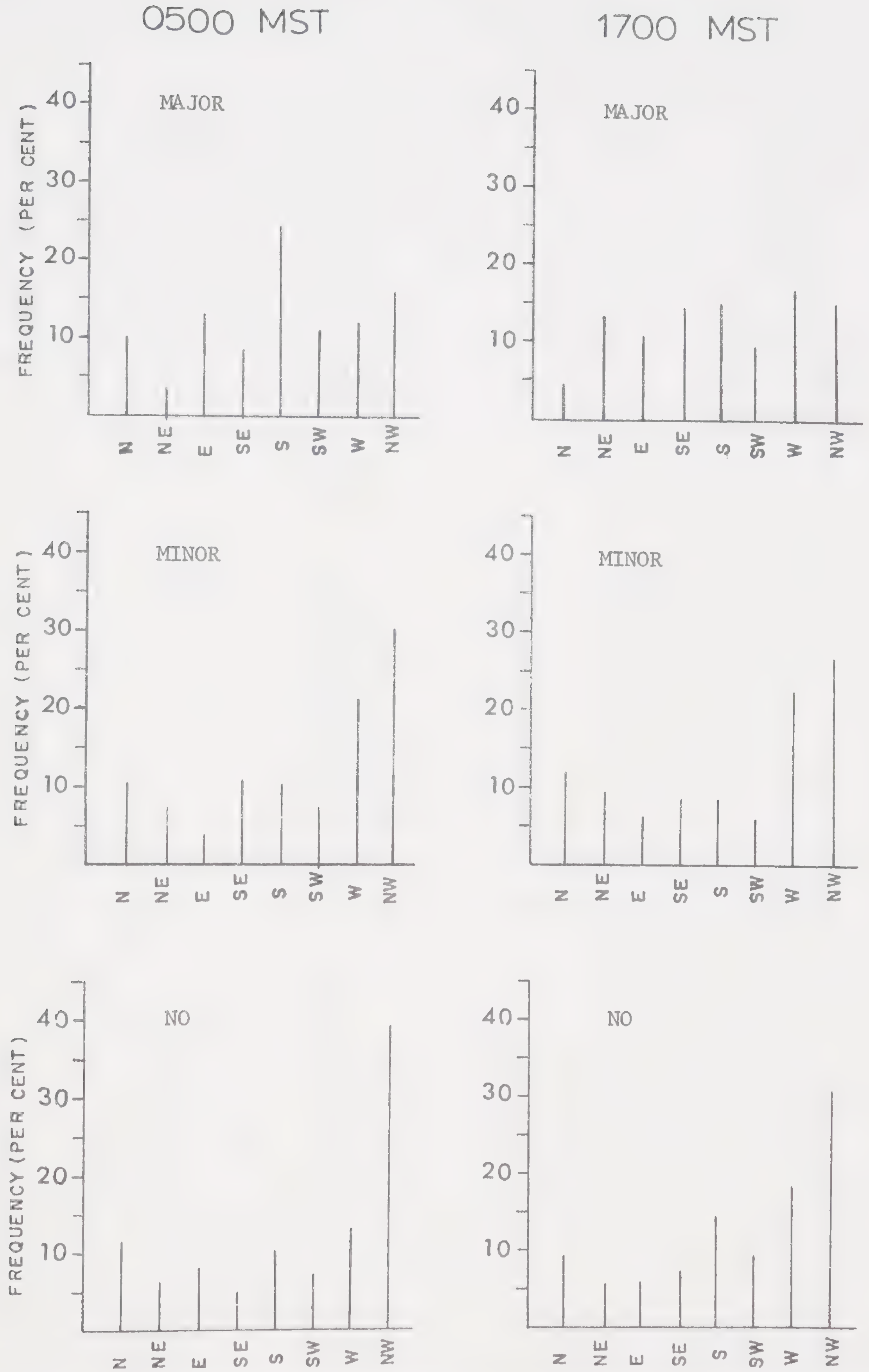

Figure 3.1 - Frequencies of winds from the different directions at the 850-mb level for each lightning class (per cent).

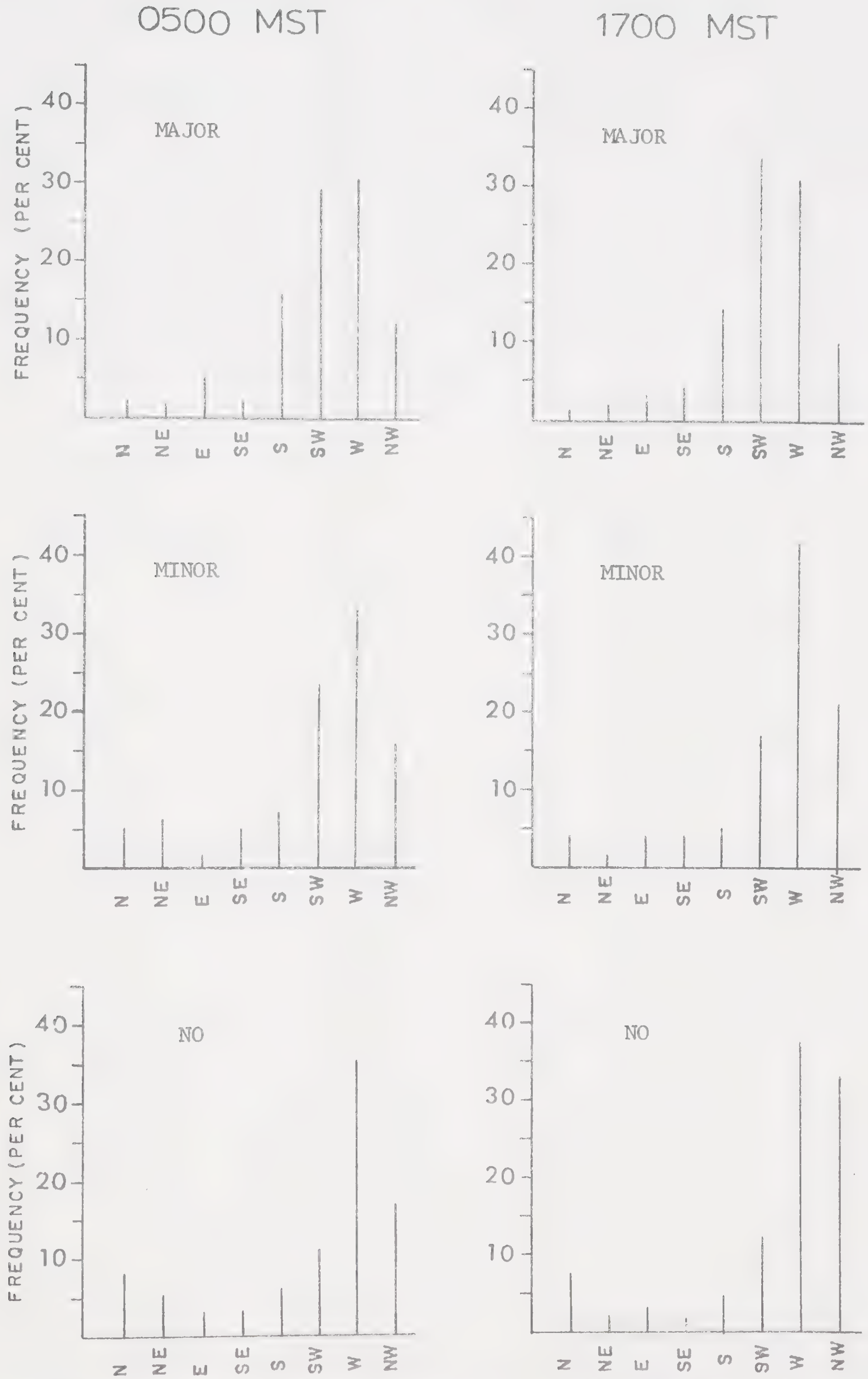

Figure 3.2 - Frequencies of winds from the different directions at the 700-mb level for each lightning class (per cent).

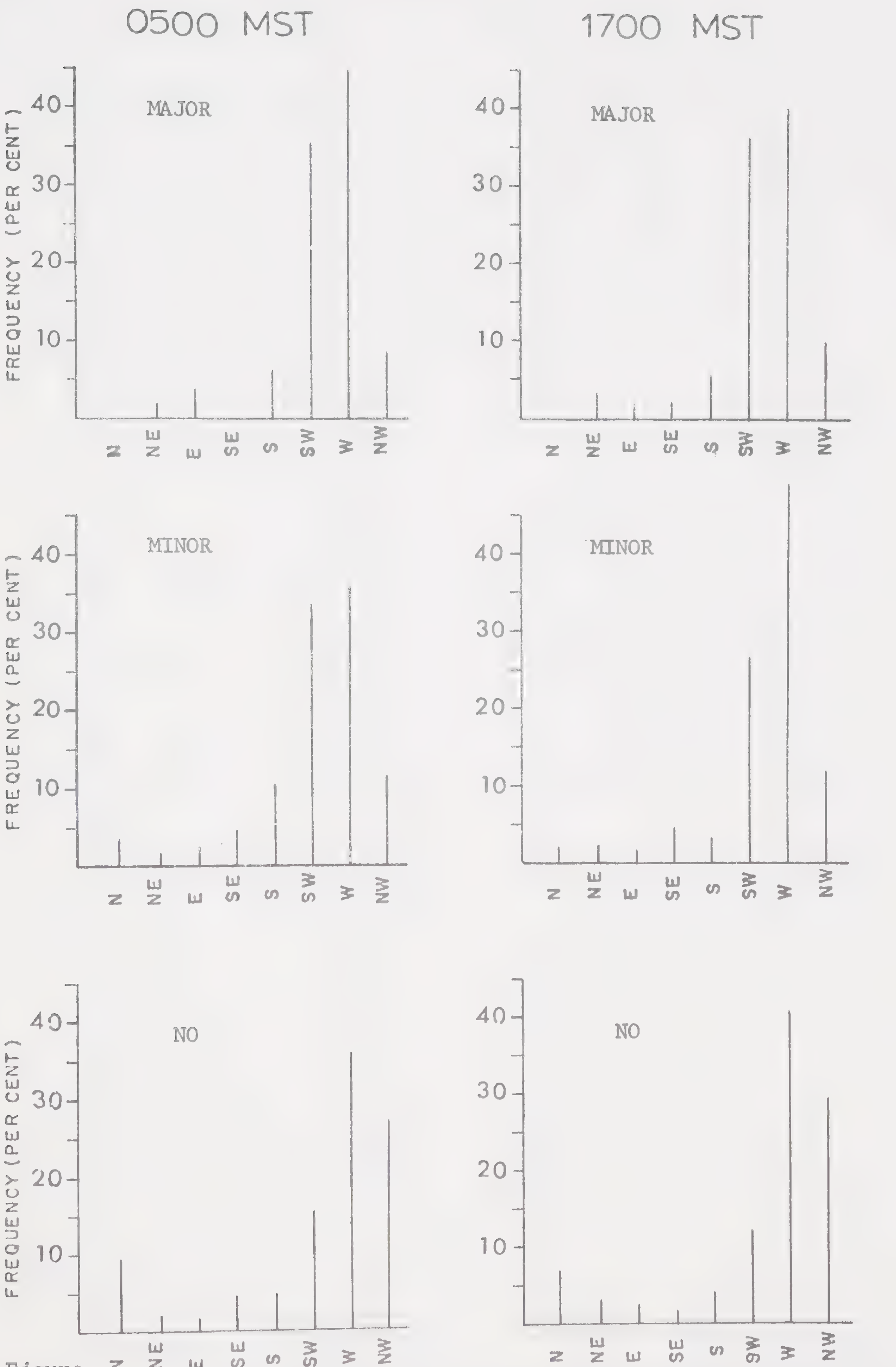

Figure 3.3 - Frequencies of winds from the different directions at the 500-mb level for each lightning class (per cent).

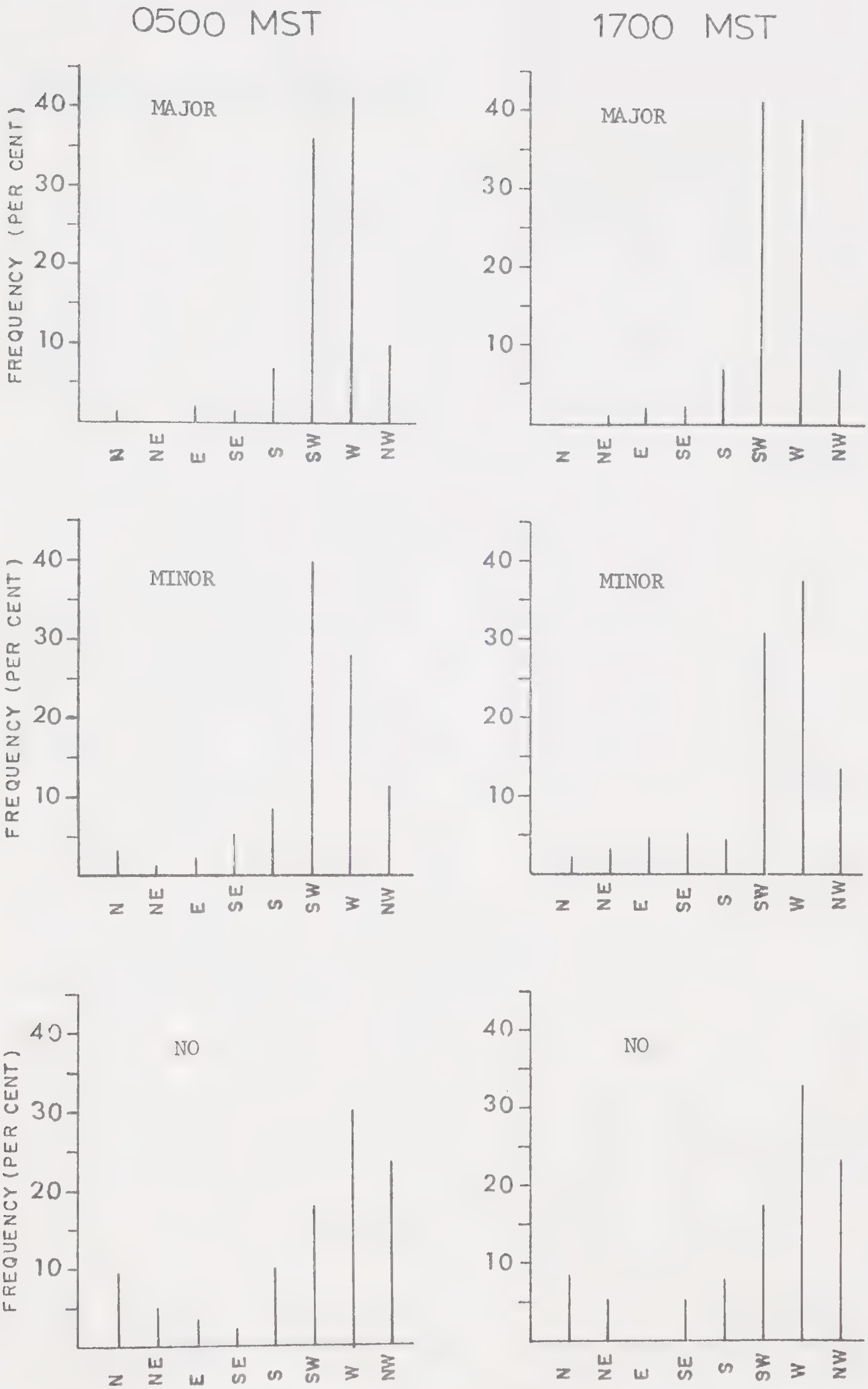

Figure 3.4 - Frequencies of winds from the different directions at the 300-mb level for each lightning class (per cent).

MAJOR-LIGHTNING UPPER WINDS

As seen on Figure 3.1, the largest proportion of major lightning days (25 per cent) is found when the 850-mb wind was from the south at 0500 MST. Proportions from other directions, except the northwest, were nearly the same and ranging from 8 to 16 per cent of the major days. Winds from the northwest direction on major days were very seldom observed at 0500 MST. At 700 mb (Figure 3.2) the wind pattern has been smoothed out and winds are observed to be more concentrated from the southwest and west. Southerly winds at 700 mb are also observed although not so frequently and northwesterly winds are less frequent than southerly winds. Winds from other directions are rarely observed. At 500 mb (Figure 3.3) the winds are very often from the west and southwest. The highest frequency is found from the west. At this level the northwesterly winds become more frequent than southerly winds, although both directions are showing very small frequencies compared to west and southwest. At 300 mb the picture is very much the same as for 500-mb level. Similar results were found at 1700 MST as shown on the same figures, except at 850-mb level where there is no distinct preferable direction for the wind on major lightning days. From the above discussion and also from examining the change of wind direction with height for the individual days, the wind tends, in general, to veer with height on major lightning days. The most general

wind pattern on major days is:

south	at 850 mb
southwest to west	at 700 mb
west to southwest	at 500 mb
west to southwest	at 300 mb

Other major lightning days having winds backing with height or an unorganized wind pattern were also observed. On these days active cold fronts and other instability conditions must have played a major role in contributing to thunderstorm occurrence. As explained by Newton (1967), a new cloud formation is favored on the right flank of an existing convective system when the wind veers with height. Thus the existence of strong vertical shear in the environment contributes to a continued regeneration of the storm by new growth.

Table 3.1 gives the mean wind speed at the standard pressure levels for winds blowing from the most frequent directions at those levels on major lightning days.

TABLE 3.1

Mean wind speed (m/s) at upper pressure levels for winds blowing from the preferred directions on major days.

	0500 MST				1700 MST			
	S	SW	W	NW	S	SW	W	NW
850 mb	9.0	5.1	6.2	7.4	6.5	3.9	4.1	8.7
700 mb	6.7	6.7	8.1	8.7	7.9	7.4	10.0	10.3
500 mb		12.6	12.3			13.8	13.2	
300 mb		21.7	21.4			25.5	20.3	

The table shows that southerly winds at 850 mb are stronger than winds from other directions at 0500 MST. They are, on the average, also stronger than the winds prevailing at 700-mb level. This will support the understanding that a low-level jet stream prior to thunderstorm occurrence will assist the release of instability (Newton, 1967). In our situation the low-level jet from the south will provide the lower levels of the area of concern with heat and moisture being advected from lower latitudes. At 1700 MST the southerly wind at 850 mb is no longer strong. Strong northwesterly winds are observed at 1700 MST apparently as a result of cold frontal passages on these days. At higher levels the southwesterly and westerly winds are frequent and are slightly stronger at 1700 MST than at 0500 MST.

MINOR-LIGHTNING UPPER WINDS

Figure 3.1 shows that northwesterly winds at 850 mb are most frequent on minor lightning days in both 0500 and 1700 MST observations. Westerly winds are also frequent on minor days. At 700 mb westerly winds become most frequent while the proportion of northwesterly winds is smaller, and the proportion of southwesterly winds is larger than at 850 mb. At 500 mb westerly winds are again the most frequent but a further decrease in the frequency of northwesterly wind is produced along with a further increase in frequency of winds from the southwest. At 300-

mb level the southwesterly winds were reported most frequently at 0500 MST. At 1700 MST the frequency of westerly winds exceeds that from the southwest by a small amount. However, the gain in the frequency of southwesterly winds from 500- to 300-mb levels at 1700 MST was met by a significant loss in westerly winds between these two levels. As a result of the above discussion and examining upper winds on the individual minor lightning days, the wind tends, on the average, to back with height on these days. The most general wind pattern on minor days would be:

Northwest to West	at 850 mb
West	at 700 mb
West to Southwest	at 500 mb
Southwest to West	at 300 mb

Although backing of wind with height tends to suppress convective activity, it will not alone inhibit thunderstorm occurrence. Backing of wind with height must then be associated with cold frontal passages which will produce strong vertical currents and some lightning.

Table 3.2 gives the mean wind speed at the upper pressure levels for winds blowing from the most frequent directions at these levels on minor lightning days. On minor days, as shown on Table 3.2 the wind is stronger at all levels than on major days (see Table 3.1). The high-level jet stream core moves toward Edmonton on minor days. It is also apparent from the 300-mb wind on Table 3.2 that the high-level jet stream turns cyclonically during a minor

day. The above discussion shows that, on the average, there is some difference in the pattern of upper winds between major and minor lightning days. Minor days tend to have wind backing with height but they are usually associated with stronger winds at all levels.

TABLE 3.2

Mean wind speed (m/s) at upper pressure levels for winds blowing from the preferred directions on minor days.

	0500 MST			1700 MST		
	SW	W	NW	SW	W	NW
850 mb		5.8	9.8		5.8	9.4
700 mb	9.0	9.9	9.4	9.6	10.2	11.7
500 mb	16.2	14.9		15.4	14.0	
300 mb	23.3	28.2		30.0	22.0	

NO-LIGHTNING UPPER WINDS

No-lightning days, as shown on Figure 3.1, are characterized mainly by a northwesterly wind at the 850-mb level. At 700 mb (Figure 3.2) westerly winds become dominant, along with a significant proportion of days reporting northwesterly wind at that level. At 500-mb and 300-mb levels (Figures 3.3 and 3.4) westerly winds remain the most frequent. It is also shown that on no-lightning days the southwesterly winds are, in general, gaining frequency as we go from lower to higher levels while the northwesterly winds are losing frequency upward.

As a result we may say that no-lightning days tend to have, on the average, winds backing slightly with height and the general pattern of wind direction on these days is as follows:

Northwest	at 850 mb
West	at 700 mb
West	at 500 mb
West	at 300 mb

Table 3.3 gives the mean wind speed at the upper pressure levels for winds blowing from the most frequent directions on no-lightning days.

TABLE 3.3

Mean wind speed (m/s) at upper pressure levels for winds blowing from the preferred directions on no-lightning days.

	0500 MST			1700 MST		
	SW	W	NW	SW	W	NW
850 mb		6.8	9.7		5.6	8.1
700 mb	6.7	10.5	11.9	7.2	11.2	10.7
500 mb	14.6	14.3	14.9	12.7	14.5	14.3
300 mb	26.5	23.3	24.8	22.6	24.2	24.4

No significant feature can be detected from Table 3.3 for the mean wind speed pattern at upper levels on no-lightning days. It becomes rather clear that minor days are generally associated with higher speeds at 300-mb level.

CHAPTER FOUR

THE CORRELATION BETWEEN WIND SHEAR AND OTHER ATMOSPHERIC PARAMETERS

In the previous chapter it was shown that days with major lightning had, on the average, winds veering with height between the 850-mb and the 300-mb levels. Minor days, on the other hand, were usually associated with backing winds upwards between the two levels. However, veering, backing and a combination of them throughout the troposphere were also observed on individual days in each class but with different proportions. It is the purpose in this chapter to select those days in each class (major and minor) which had winds veering with height between the 850-mb and 300-mb levels and those days which had winds backing between the same two levels and examine the relationship between wind shear and other weather parameters discussed earlier. The wind pattern between the surface and the 850-mb level does not take part in the analysis. A study of these winds could, perhaps, add to our knowledge of the relationship between winds and thunderstorm occurrence. Table 4.1 gives the number of days in major and minor classes which reported a vertical shear of one type (veering or backing) between 850-mb and 300-mb levels. Table 4.2 shows the mean wind shift (in degrees) between the adjacent pressure levels. For example, by examining the 39 major lightning days which had winds veering with height, there was a mean shift in

wind direction of 58 degrees between the 850-mb and 700-mb levels at 0500 MST. Most of the no-lightning days were characterized by very little wind shear of unsteady pattern between 850- and 300-mb levels. Therefore, the no-lightning class will not be included into the following discussion.

TABLE 4.1

Number of days in major and minor lightning classes which had veering (V) and backing (B) winds between the 850- and 300-mb levels.

	0500 MST		1700 MST	
	V	B	V	B
Major	39	19	36	27
Minor	31	31	31	41

TABLE 4.2

Mean wind shift between the adjacent pressure levels when the wind was veering (V) and backing (B) on lightning days (degrees).

	0500 MST				1700 MST			
	MAJOR		MINOR		MAJOR		MINOR	
	V	B	V	B	V	B	V	B
850-700	58	49	33	48	61	55	60	49
700-500	22	25	26	26	16	22	19	21
500-300	6	17	9	14	9	21	5	19

Table 4.2 shows that on lightning days the veering of winds occurred largely in the lower layers while backing of winds extended appreciably to higher levels.

THE VERTICAL TEMPERATURE PROFILE

The mean temperature at the surface and at the upper pressure levels were calculated for each of the above groups of days (see Table 4.1) and a mean temperature profile is plotted on a tephigram. Figures 4.1 and 4.2 show the mean soundings for days of veering and backing winds of the major class at 0500 and 1700 MST respectively. Figures 4.3 and 4.4 show similar curves for the minor class. As shown on the figures, the days of veering winds, on the average, are characterized by a warmer sounding throughout the troposphere than on days of winds backing with height. This agrees with the fact that veering is associated with warm air advection and backing is associated with cold air advection. Strong warming takes place in the surface layer between 0500 and 1700 MST when the wind between 850 mb and 300 mb veers with height. It is also seen that major lightning class has a larger temperature difference between days of veering winds and days of backing winds than minor class.

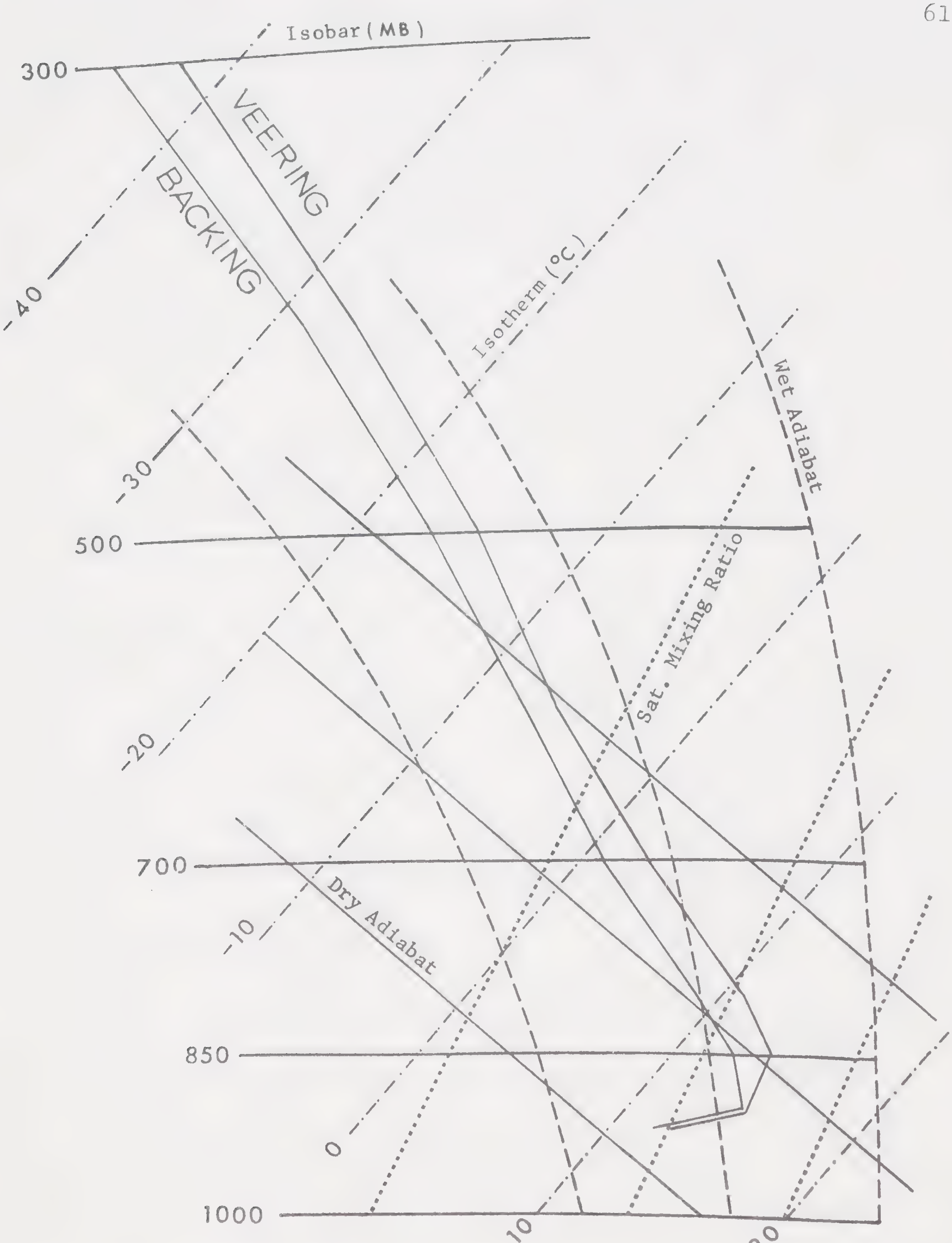

Figure 4.1 - Mean 0500 MST soundings for days of veering and backing winds in the MAJOR lightning class.

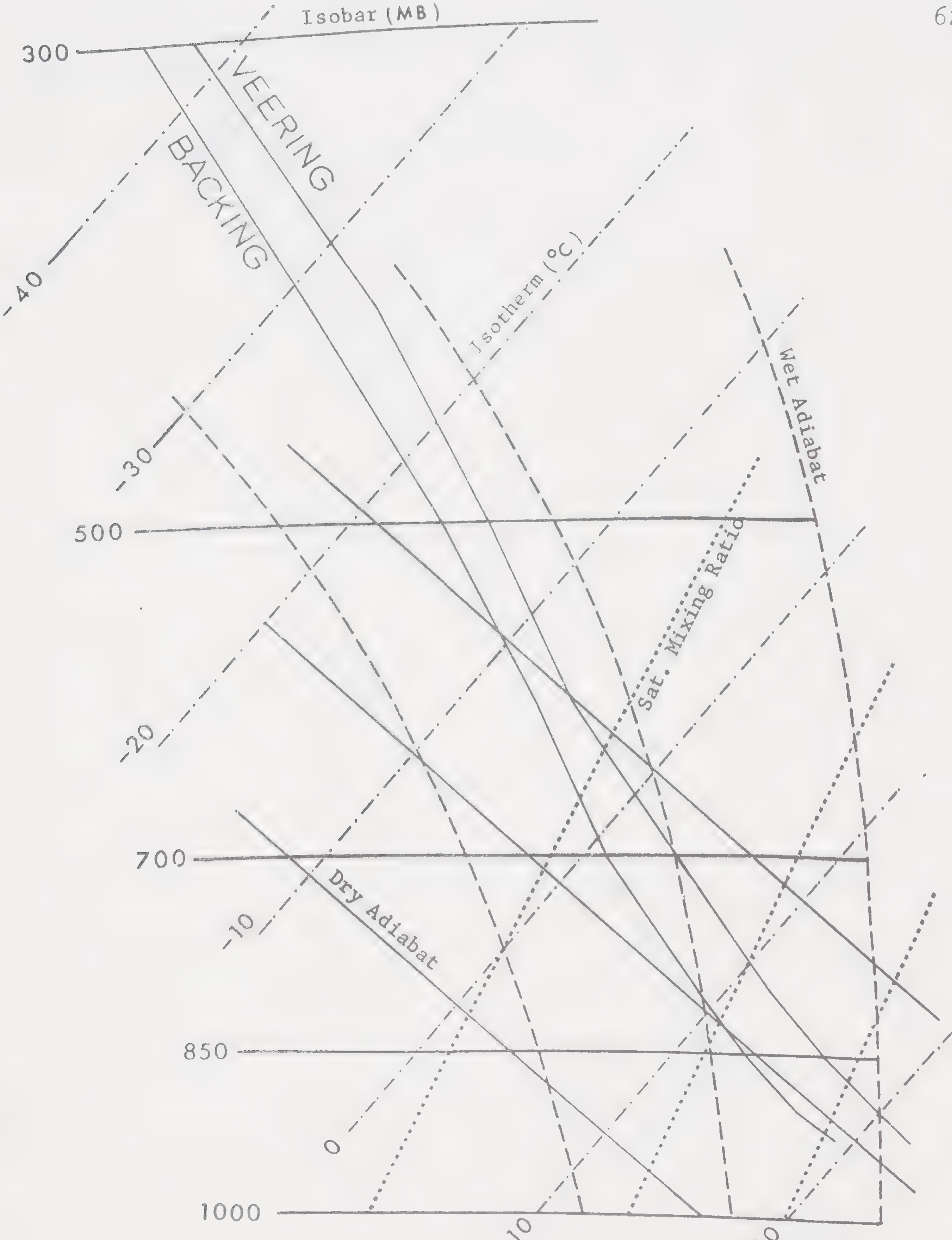

Figure 4.2 - Mean 1700 MST soundings for days of veering and backing winds in the MAJOR lightning class.

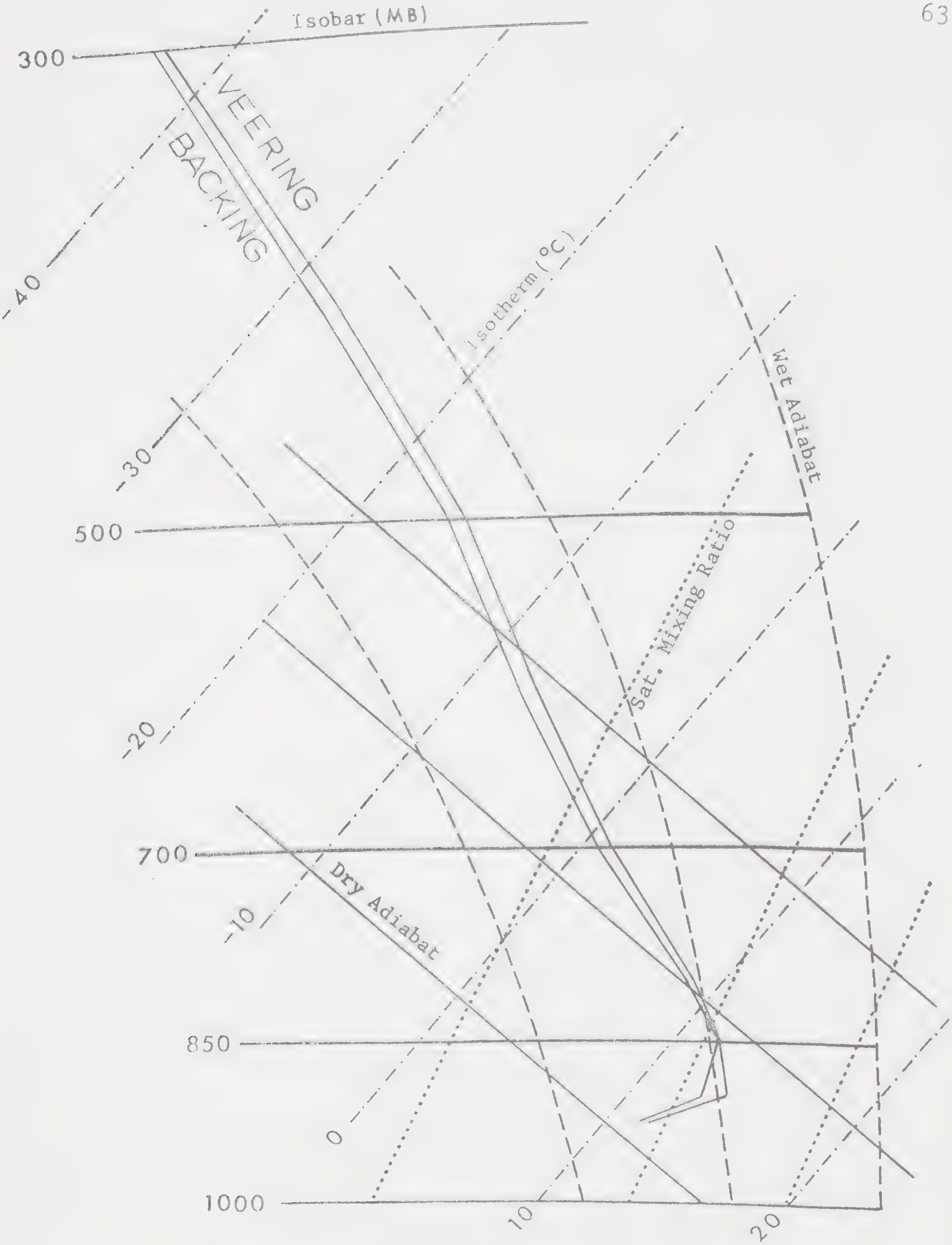

Figure 4.3 - Mean 0500 MST soundings for days of veering and backing winds in the MINOR lightning class.

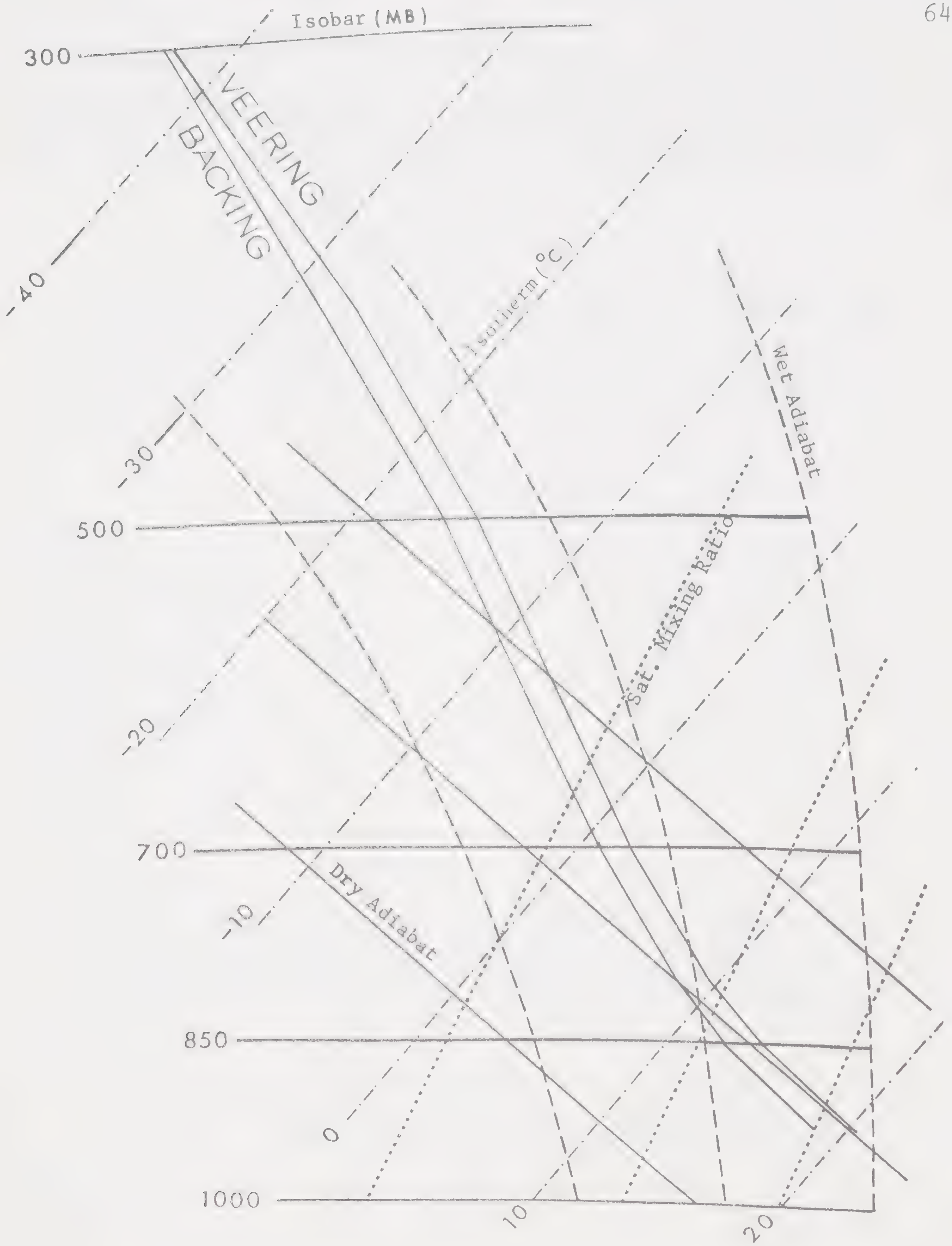

Figure 4.4 - Mean 1700 MST soundings for days of veering and backing winds in the MINOR lightning class.

Tables 4.3 and 4.4 show the correlation coefficients between the temperatures of lower and upper levels of the troposphere on major and minor days respectively.

TABLE 4.3

The correlation coefficients between the temperatures of lower and upper levels of the troposphere in the presence of different wind shears on MAJOR lightning days.

	0500 MST		1700 MST	
	VEERING	BACKING	VEERING	BACKING
Surface & 600 mb	.45	.77	.62	.67
Surface & 500 mb	.53	.79	.56	.68
Surface & 300 mb	.52	.77	.54	.60
850 mb & 500 mb	.78	.91	.61	.80
850 mb & 300 mb	.76	.87	.59	.68

TABLE 4.4

The correlation coefficients between the temperatures of lower and upper levels of the troposphere in the presence of different wind shears on MINOR lightning days.

	0500 MST		1700 MST	
	VEERING	BACKING	VEERING	BACKING
Surface & 600 mb	.34	.89	.48	.51
Surface & 500 mb	.51	.90	.41	.52
Surface & 300 mb	.27	.81	.33	.35
850 mb & 500 mb	.61	.81	.61	.65
850 mb & 300 mb	.48	.72	.53	.44

In the two tables, smaller correlations between lower and upper levels indicate larger instability in the air column in the sense that strong warming in the lower levels is associated with little warming aloft; and little cooling in the lower levels is associated with strong cooling aloft. Of course, small correlations could also arise from the case of large stability in the air column but this was assumed not to occur on a lightning day. The results of Tables 4.2, 4.3 and 4.4 show that when the wind is veering with height on lightning days, there is strong warming in the lower layers accompanied with little warming aloft. As backing of wind with height, i.e. cold air advection, took place also on lightning days we may expect that passages of cold fronts on these days were the controlling mechanism in releasing instability and producing lightning activity.

STABILITY INDICES

The mean values of the surface pressure, low-level moisture, Showalter index, and the Totals index were calculated for each group of days having a vertical wind shear of one type (see Table 4.1). No differences of any significance were found between these means for veering and backing winds. However, the correlations between some of the above indices were found to be significantly different for veering and backing winds. The correlation coefficients are given in Table 4.5 for major and minor days at 0500 MST.

TABLE 4.5

The correlation coefficients between stability indices for different wind shears at 0500 MST.

	MAJOR		MINOR	
	VEERING	BACKING	VEERING	BACKING
Sur. press. & low level moisture	-.36	-.29	-.33	-.13
Sur. press. & Showalter	.36	-.03	.43	.04
Sur. press. & Total Total	-.23	.16	-.42	.09
Low level moisture & Showalter	-.72	-.44	-.52	-.42
Low level moisture & Cross Total	.47	-.04	.39	.23
Low level moisture & Total Total	.51	.15	.29	.03
Showalter & Vertical Total	-.67	-.62	-.47	-.37
Showalter & Cross Total	-.72	-.72	-.47	-.81
Cross Total & Total Total	.79	.88	.52	.82

The table shows that the absolute values of the coefficients are greater for veering than for backing winds except in the last two correlations. Similar results were also found at 1700 MST for the major class only. From the above discussion we may say that on major lightning days the correlations between the stability indices were generally higher for veering than for backing winds in both 0500 and 1700 MST observations. On minor days, the correlation was smaller with veering winds at 1700 MST although some indices may have been present in strength on these days. Again here, we may generally speak of higher instability in the air column when the wind is veering with height. Backing winds are expected to be associated with cold fronts on lightning days.

Days having winds veering with height in the lower troposphere along with winds backing in the middle and upper troposphere were also found in major and minor classes. These days were characterized by warm air advection in the lower levels and cold air advection aloft. As a result, there was sufficient instability in the air column to produce air-mass thunderstorms on these days. Other lightning storms may have occurred due to the vertical motion induced by unstable warm air rising over a wedge of cold air.

CHAPTER FIVE

CONCLUSIONS

Observations show that thunderstorms often occur in more or less distinct patterns, and it is customary to speak of air-mass thunderstorms, line thunderstorms and frontal thunderstorms. Air-mass thunderstorms develop locally where the lapse rate has become steep, e.g., as a result of diurnal heating. Line thunderstorms are organized into narrow belts or bands in the direction of the winds at low levels. Frontal thunderstorms develop usually with cold fronts if the warm air is convectively unstable and they move along with the fronts. Although there was no distinction made in this study to the type of thunderstorm which caused lightning, the difference between the effect of frontal and air-mass thunderstorms was recognized in several parts of this work. In what follows, concluding remarks will be given for each of the parameters studied earlier.

THE VERTICAL TEMPERATURE PROFILE

The vertical distribution of temperature on lightning days is different from that on no-lightning days. Major days are usually warmer by about 2.5 to 4 C than no-lightning days in the lower layer and by smaller amounts at higher levels. Minor days reported 2 to 3 C higher than no-lightning days in the lower layer but there was a small difference aloft. As a result, addition of heat to the lower levels of the troposphere assists thunderstorms to develop although

mechanical lifting by fronts may be enough for their occurrence. In the present study the warming on lightning days was appreciable up to the 650-mb level and it was maximum in the 850- to 800-mb layer.

THE LOW LEVEL MOISTURE

The formation of cumulonimbus clouds requires a high moisture content in the atmosphere. Low-level moisture represents the main supply of water vapor to the cloud formation. Although the threshold value of the lowest 50-mb mixing ratio is 3 g/kg for having a lightning day as shown on Figures 2.3 and 2.4, the probability of lightning occurrence does not become 50 per cent unless the low-level mixing ratio is over 7 g/kg. High moisture content on no-lightning days must be associated with stability conditions such as subsidence or low-level cold air advection and a high-level warm air advection.

SURFACE PRESSURE AND ITS RATE OF CHANGE

Surface pressure alone does not distinguish well between the different classes. It has a wide range of values on lightning days. Surface pressure may be used as a restrictive parameter for it is noticed that lightning occurrence in Whitecourt region reduced when the station pressure of Edmonton Stony Plain (766 m) was above 928 mb during the day. The 12-hour change in surface pressure did not discriminate well between minor lightning and no-lightning at 1700 MST. At 0500 MST there was a distinction between

lightning and no-lightning days but a little difference between major and minor lightning. This parameter should then be used carefully when preparing a lightning forecast.

RATE OF CHANGE IN 500-MB HEIGHT

The 12-hour change in 500-mb height separates lightning and no-lightning days in general but it has little significance to the occurrence of major lightning as shown on Figures 2.8 and 2.9. If a rise of 50 m or more takes place at 500-mb level between 0500 and 1700 MST, the incidence of lightning drops sharply while a fall of 50 m or more will give a probability more than 75 per cent that lightning occurs during the day.

THE SHOWALTER INDEX

The Showalter index best differentiated among the three lightning classes. The probability distributions of Figures 2.10 and 2.11 show that a negative value of Showalter index at 0500 MST or 1700 MST produces a probability more than 70 per cent that lightning occurs during the day. The probability increases to 95 per cent if the index value reaches -3 and decreases sharply if it is above +5.

THE TOTALS INDEX

The three totals indices reliably distinguish between lightning and no-lightning in general. The Total Total is very highly correlated with the Showlater index as both measure basically the same thing. The Total Total may then be used instead of the Showalter index for forecasting

lightning. Great attention must be paid to a few cases where the lapse rate will be steep, giving rise to a high Vertical Total with a little support of moisture. Otherwise, the three totals indices can be useful in lightning prediction. A large number of lightning days reported values of Total Total greater than 44, values of Cross Total greater than 17 and values of Vertical Total greater than 27 at 1700 MST.

THE WET BULB ZERO HEIGHT

The previous results show that lightning days are usually associated with higher wet bulb zero level. A large number of lightning days were characterized by a height of wet bulb zero between 2700 m and 3900 m. The wet bulb zero height may not be used alone as a single predictor as it gives a little distinction between lightning and no-lightning days. Cold fronts lower the wet bulb zero considerably and yet they produce lightning activity.

THE SURFACE MAXIMUM TEMPERATURE

The maximum temperature at the surface is useful for the air-mass thunderstorms but it has little significance otherwise. Over the number of days studied here, this parameter proved that it can not be used alone to give a reliable forecast of lightning.

THE UPPER-LEVEL WIND

On major lightning days, veering of wind with height was observed more than backing. At 850-mb level winds from

the south were observed more than from any other direction. This southerly wind was also strong and it transported heat and moisture to the lower layers on major days. The wind shift on veering days happened to be largely in the lower levels as it is associated with warm air advection at these levels.

On minor days, backing of wind with height was more frequent. On these days it may be said that cold fronts passing over the region represent the important mechanism in lightning occurrence. The high-level wind was stronger on minor days.

On no-lightning days there was little wind shift with height and the change was probably due to cold air advection in low levels and warm air advection aloft.

In several cases of lightning days there was veering of wind in the lower levels and backing of wind aloft. These situations must also be characterized by high instability due to warm air advection below and cold air advection aloft.

GENERAL REMARKS

In this study the weather information of Edmonton Stony Plain was taken to represent the air overlying the Whitecourt region. On some occasions, because of the distance between the two localities, the air mass over Whitecourt will not be represented by the data from Stony Plain.

In addition to the above remark, it should also be

realized that the lookout men do not observe the weather during the night. This could result in a lightning day which was actually classified as "no-lightning day" in the previous analysis. Other missing reports from the lookouts may have given rise to inaccurate classification of days.

In spite of the above mentioned possible errors and of the short term statistics, this study has shown that weather parameters and stability indices can be useful in distinguishing between lightning and no-lightning weather conditions. It is hoped that the given results will be helpful to the forecaster in predicting occurrence of lightning.

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